# NAVAL POSTGRADUATE SCHOOL
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# THESIS

**A MULTI-COMMODITY NETWORK DESIGN FOR THE DEFENSE LOGISTICS AGENCY**

by

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June 1994

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The Defense Logistics Agency (DLA) currently operates 28 depots in the United States from which it supplies over 45,000 customers with over 3 million products procured from over 10,000 suppliers. DLA plans to reduce its infrastructure and proposes to analyze its distribution system using the Strategic Analysis of Integrated Logistics Systems (SAILS) model - a mixed integer linear programming model widely used by a number of civilian organizations to make facility location decisions. The size of DLA's distribution system precludes directly evaluating all possible depot, product, and customer combinations. This thesis derives a 29 product, 113 customer aggregation scheme which facilitates SAILS execution and appears to adequately model DLA. Extensive comparisons between this aggregation scheme and others (44-, 49-, and 67-product; and 199- and 113-customer aggregations) at 100, 90, 80, 50, and 30 percent of derived depot throughput capacity show solutions to different aggregations result in virtually identical closure recommendations and total annual cost. This thesis shows how DLA can save over 300 million dollars annually through depot closure and reorganization.

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A Multi-Commodity Network Design for the Defense Logistics Agency

by

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## ABSTRACT

The Defense Logistics Agency (DLA) currently operates 28 depots in the United States from which it supplies over 45,000 customers with over three million products procured from over 10,000 suppliers. DLA plans to reduce its infrastructure and proposes to analyze its distribution system using the Strategic Analysis of Integrated Logistics Systems (SAILS) model - a mixed integer linear programming model widely used by civilian organizations to make facility location and logistics network design decisions. The size of DLA's distribution system precludes directly evaluating all possible depot, product, and customer combinations. This thesis derives a 29 product, 113 customer aggregation scheme which facilitates SAILS execution and appears to adequately capture sufficient detail to accurately model DLA. Extensive comparisons between this aggregation scheme and others (44, 49, and 67 product; and 199 and 113 customer aggregations) at 100, 90, 80, 50, and 30 percent of derived depot throughput capacity show solutions to different aggregations result in virtually identical closure recommendations and total annual costs. This thesis shows how DLA can save over 300 million dollars annually through depot closure and reorganization.

## TABLE OF CONTENTS

I. INTRODUCTION .... 1

A. DEFENSE LOGISTIC AGENCY .... 2

B. OBJECTIVE OF CURRENT RESEARCH .... 3

C. THESIS OUTLINE .... 4

II. RELATED STUDIES .... 5

A. DEPARTMENT OF DEFENSE MATERIAL DISTRIBUTION SYSTEM (DODMDS) STUDY .... 5

B. OTHER STUDIES .... 8

1. Product Aggregation .... 9

2. Geographic Customer Aggregation .... 11

3. Supplier Aggregation .... 16

III. AGGREGATION SCHEMES .... 18

A. PRODUCT AGGREGATIONS .... 18

B. CUSTOMER AGGREGATIONS .... 23

C. SUPPLIER AGGREGATIONS .... 25

D. TRANSPORTATION MODE AGGREGATIONS .... 27

E. DEPOT AGGREGATIONS .... 31

IV. COMPUTATIONAL EXPERIENCE .... 34

A. DATABASE .... 34

1. Transaction File .... 34

2. Facilities .... 36

B. RUN DESCRIPTIONS .... 39

C. RESULTS........................................ 40

V. CONCLUSIONS AND RECOMMENDATIONS ....................... 58

A. CONCLUSIONS.................................... 58

B. RECOMMENDATIONS................................ 59

APPENDIX A: SAILS FORMULATION............................ 61

APPENDIX B: FEDERAL SUPPLY CLASSIFICATION PRODUCT GROUPS.. 64

APPENDIX C: FEDERAL SUPPLY CLASSIFICATION LISTING......... 65

APPENDIX D: COMMODITY AGGREGATIONS........................ 72

APPENDIX E: CUSTOMER AGGREGATIONS......................... 81

LIST OF REFERENCES....................................... 86

INITIAL DISTRIBUTION LIST................................ 89

## EXECUTIVE SUMMARY


This thesis shows how the Defense Logistic Agency (DLA) can save over 300 million dollars annually through depot closure and reorganization. This conclusion follows extensive analysis of DLA's distribution network using the Strategic Analysis of Integrated Logistics Systems (SAILS) model - a mixed integer linear programming model widely used by civilian organizations to make facility location and logistics network design decisions. This thesis derives a 29-product, 113-customer aggregation scheme which facilitates SAILS execution and appears to adequately capture sufficient detail to accurately model DLA. Extensive comparisons between this aggregation scheme and others (44-, 49-, and 67-product; and 199- and 113-customer aggregations) at 100, 90, 80, 50, and 30 percent of derived depot throughput capacity show solutions to different aggregations result in virtually identical closure recommendations and total annual cost.

The Defense Logistics Agency (DLA) currently operates 28 depots in the United States from which it supplies over 45,000 customers with over three million products procured from over 10,000 suppliers. DLA must reduce operating costs to accommodate declining Defense budgets. Consequently, a number of facilities has been slated for closure or realignment under the Defense Base Realignment and Closure (BRAC) Commission's 1991 and 1993 recommendations. DLA will plan further closures for 1995 using the Strategic Analysis of Integrated Logistics Systems (SAILS)

model. The size of DLA's distribution system precludes directly evaluating all possible depot, product, and customer combinations. Without aggregation, data input and output would be overwhelming even if sufficient computer memory, computational ability, and storage exist to solve the resulting SAILS' mixed integer linear program.

Even with aggregation, modeling of DLA's extensive distribution system requires enormous amounts of data. This thesis uses the following information supplied by DLA: the 1992 Material Release Order files containing over 17 million material shipment transactions totaling over 1 billion pounds from which demand and customer information is obtained, depot fixed and variable costs, and depot throughput capacity information. Because of difficulty obtaining and manipulating the required files, this thesis does not directly model subsistence material which accounts for approximately 25 percent of total demand weight. Instead, it uses a conservative estimate of the depot throughput capacity. From all data, a 29-product, 113-customer aggregation scheme is developed and extensively tested on a 586 66 MHz personal computer with 261 megabytes of extended memory.

Solutions produced using the various aggregation schemes indicate that significant annual savings of over 300 million dollars can be realized from depot closures and reorganization. Recommended closures decrease fixed and variable costs by approximately 349 million dollars while increasing transportation costs by 13.5 million dollars.

# I. INTRODUCTION

The Defense Logistics Agency (DLA) must reduce it operating costs to accommodate declining Defense budgets. Consequently, a number of facilities has been slated for closure or realignment under the Defense Base Realignment and Closure (BRAC) Commission's 1991 (BRAC Commission [1991]) and 1993 (BRAC Commission [1993]) recommendations. DLA will plan further closures for 1995 using the Strategic Analysis of Integrated Logistics Systems (SAILS) model (INSIGHT Inc. [1993]). SAILS is a computer program widely used by civilian companies to make plant location, warehouse location, and inventory positioning decisions (Appendix A contains the underlying mixed integer linear program at the heart of SAILS). The size of the DLA's distribution system precludes directly evaluating all possible depot, product, and customer combinations. Without aggregation, data input and output would be overwhelming even if sufficient computer memory, computational ability, and storage exist to solve the resulting SAILS' mixed integer linear program. This thesis defines aggregation schemes for DLA products, customers, and suppliers for use in SAILS.

## A. DEFENSE LOGISTICS AGENCY

DLA's primary mission is timely provisioning of consumable material to Department of Defense activities during either peacetime or wartime. DLA's problem is how to maintain the current level of customer service while closing existing facilities and reducing operating costs. House [1978] succinctly states DLA's dilemma:

> The importance of the facility location problem is due primarily to the fact that distribution centers represent significant cost centers in the distribution channel... distribution depots represent points where customer service is provided through the maintenance of inventories. In many situations, it can be shown that as more facilities are sited there is a proportional increase in the amount of customer service provided...[House 1978 p. 1]

The DLA distribution system is primarily a two-echelon system where materials flow in large shipments from suppliers to depots and from these depots in smaller order quantities to the ultimate consumers. A small amount of material flows directly from vendor to customer but suppliers do not necessarily remain constant over time, and therefore this thesis models DLA's distribution system as a pure two-echelon system with no direct vendor to customer flows.

DLA manages a diverse mix of material including subsistence items, aircraft repair parts, clothing, paper products, fuel, medicines, and construction material (DLA, [1992]). To operate the distribution system, DLA has:

- six inventory control points responsible for inventory management of over three million line items.

- 28 distribution depots located throughout the United States responsible for the receipt, storage, and distribution of this material [DLA, 1992].

DLA has recently assumed greater responsibilities as the Department of Defense (DOD) attempts to reduce operating costs by consolidating operations. As the result of Defense Management Review Decisions (DMRD) issued by the Secretary of Defense [1989], the following actions have increased DLA's responsibilities:

- Consumable items previously managed by the individual services have been transferred to DLA; this action has the potential to increase the range of materials managed by 981,000 line items (DMRD 926 [1989]).
- Distribution depots previously operated by the individual services have been transferred to DLA which increased DLA's total number of depots to thirty two (DMRD 902 [1989]).

## B. OBJECTIVE OF CURRENT RESEARCH

This study develops aggregation schemes for DLA products, customers, and suppliers which allow DLA's distribution system to be modeled within SAILS and allows SAILS' underlying mathematical model to be solved in a reasonable time without significant loss of fidelity. To evaluate the validity of the aggregation techniques, several commodity and customer aggregation schemes are formulated. Comparisons are made between the solutions generated from the different techniques highlighting significant variation. The base year for purposes of this study is fiscal year 1992. Historical files for fiscal year 1992 show that DLA:

- procured material from over 10,000 suppliers;
- processed and shipped over fifteen million requisitions with a total weight of over one billion pounds; and
- served over 45,000 customers including all military services and other government activities.

## C. THESIS OUTLINE

Chapter II discusses the 1978 Department of Defense Material Distribution System (DODMDS) study and related literature. Chapter III discusses the aggregation schemes developed. Chapter IV provides computational experience. Chapter V presents conclusions and recommendations. Appendix A contains the underlying mathematical model used by SAILS. Appendix B provides a listing of the material groupings managed by DLA. Appendix C presents a statistical summary of the material transaction file supplied by DLA for this study. Appendix D details the four different commodity aggregation schemes. Appendix E describes the customer aggregation schemes.

# II RELATED STUDIES

The DLA distribution system was examined in 1978 by the Department of Defense Material Distribution System (DODMDS) study, a joint service effort commissioned after the Vietnam War to reduce DOD operating costs. The purpose of this study was to examine the existing distribution system and recommend improvements which would support individual Service operational requirements in an effective and efficient manner. This chapter reviews this study and studies accomplished on civilian distribution networks which are useful as a foundation for developing aggregation schemes.

## A. DEPARTMENT OF DEFENSE MATERIAL DISTRIBUTION SYSTEM (DODMDS) STUDY

The DODMDS study, undertaken in April 1975, examined the distribution systems operated by the Army, Air Force, Navy, Marines, and DLA within the fifty United States. This study examined the entire DOD distribution network which included maintenance depots as well as storage facilities. All material managed by these services and required within the United States and overseas was included with the exception of the following products: bulk petroleum, perishable subsistence; ammunition; chemical, biological, and radiological items; industrial plant equipment; and some major end items (i.e., ships, aircraft, and strategic missiles) (DODMDS [1978] Vol I p. 9). Because of the inclusion of repairable components and the need for this type of material to be returned to maintenance facilities for repair, the material return network was examined as well. Released in 1978, the study provided an optimal distribution network for DOD, but these results were never implemented.

The DODMDS study group acknowledged a problem which is inherent in any examination of a system this extensive where data aggregation is required:

> Large scale studies have frequently been criticized for aggregating a problem out of existence and unwittingly biasing the results through the aggregation process. (DODMDS [1978] Vol I p. 27)

DLA agreed with this criticism. In their opinion, data aggregation significantly reduces the variability associated with individual items and demand locations (DLA [1978]). The major assumption underlying the DODMDS study is demand stability and this situation is not always the case with DLA's demand patterns. Hobbs and Lanagan [1992] find that demand stability for DLA requirements is an erroneous assumption. According to their study, demand variability exists on three levels:

- Examining total demand across all commodities and over a 10 year period, annual demand experiences a 33 percent decrease from a peak year to the minimum period;

- Within two commodities examined individually (Electronics and General), annual demand decreases approximately 25 and 30 percent respectively over a seven year period;

- Using two different populations of items and the six original DLA depots (Mechanicsburg, Richmond, Memphis, Columbus, Ogden, and Tracy), Hobbs and Lanagan examine the workload variability for these depots over a two year period. For population A (103,000 items), these depots experience shifts in the number of transactions from an increase of 10 percent to a decrease of 3 percent and decreases in shipment quantities from 12 percent to 20 percent. For population B (219,000 items), the number of transactions vary from an increase of 9 percent to a decrease of 7 percent and the quantities shipped vary from a plus of 2 percent to a minus 23 percent;

- Using the same two population groups (population A, 103,000 items and population B, 219,000 items) and 11 customer groupings, Hobbs and Lanagan examine the variability of demand within customer clusters over a two year period. For population A, the number of transactions processed vary from a plus 8 percent to a minus 6 percent and the actual quantities shipped varies from a minus 3 percent to a minus 29 percent. For population B, the number of transactions vary between a plus 4 percent to a minus 16 percent while the actual quantities shipped varies from a minus 3 percent to a minus 26 percent.

These results show that customer demand may not be stable between periods for a geographic location but offer no predictive estimates of future demand patterns. Experience with SAILS in the private sector (Karrenbauer [1994]) has shown that demand variability with commercial organizations far exceeds that reported by Hobbs and Lanagan [1992] and that DLA's distribution network can be meaningfully accommodated by SAILS. SAILS develops a optimal strategic distribution network (*i.e.*, determines optimal depot locations for the network operating over a long time-frame) as opposed to a tactical or operational plan designed to make daily decisions.

This study, like the DODMDS study, bases its analysis and conclusions on one year's historic data.

The aggregation techniques utilized in the DODMDS study are used as a template for the schemes of this current study. Specific similarities and differences between the aggregations of the DODMDS study and the ones presented in this thesis are addressed in follow on chapters.

## B. OTHER STUDIES

In recent years substantial research has been accomplished discussing location analysis for plants, distribution facilities, retail activities, and service centers (House [1978]; Geoffrion [1976]; Geoffrion and Graves [1974]; Ghosh and Mclafferty [1987]; Khumawala and Whybark [1971]; Klincewicz [1985]; Neebe and Khumawala [1981]; Cooper [1967]; Geoffrion and Powers [1993]). According to Geoffrion and Powers [1993 p. 2], these studies have resolved the following basic distribution network planning questions:

- How many distribution centers should there be and where should they be located?
- What size should each distribution center be and what products should it carry?
- What distribution center (plant) should service each customer?
- Should all stocking points carry all products or specialize by product line?
- How should each plant's output be allocated among distribution plants/customers?

* What should the annual transportation flows be? Should pool points be used, and if so where should they be?

* For a given level of customer service, what is the cost savings for the proposed system?

On the other hand, there has been limited research conducted on the aggregation techniques necessary to facilitate data input into these models and the results these schemes have on final solutions. As House and Jamie [1981] state:

> Research conducted in the past several years has focused almost exclusively on techniques employed in planning... very little research appears to have been conducted in determining the sensitivity of planning results to the methods employed in aggregating data.(House and Jamie [1981])

Recent improvements in computers and the location models allow inputs to be much more voluminous and detailed than previously, but data aggregation is still necessary. Bender acknowledges the importance of aggregating data correctly:

> The most critical step in the analysis and design process is to determine the right level of data aggregation: the more aggregated the data, the greater the potential errors in analysis, but the simpler it is to analyze, and the cheaper it is to assemble. (Bender [1985] p. 157)

### 1. PRODUCT AGGREGATION

DLA manages over three million line items. Recognition of each of these products individually is impractical for any facility location model thus some product aggregation is required.

To aggregate products there are *four factors according* to Bender which must be considered: (Bender [1985] p. 157)

- Market: identify the top products which account for the bulk of material shipped; account for the different sales ratios in the various markets;
- Logistic: aggregate products with similar transportation rates, handling, and storage characteristics;
- Production: aggregate products with similar unit production costs and those produced in the same plants; and
- Organizational: aggregate products based on any unique requirements of the organization.

The aggregation studies reviewed in this thesis have not concentrated on product aggregations. These studies (House and Jamie [1981]; Ballou [1991] and [1993]) examine distribution systems comprised of a limited number of consumer oriented products or product lines where the need to aggregate has not been considered or the aggregation scheme is straightforward. With product aggregation, the variability inherent in individual products is reduced. Ballou [1991] diminishes the importance of product differences concluding that these differences did not play a major factor in demand cluster determinations:

> Different transport rates associated with different products do not significantly affect the number of clusters to be used or the manner in which the clusters are formed... product differences and their shipment sizes can be eliminated as an important variable in the selection of demand clusters. (Ballou [1991] p. 14)

Civilian distribution systems typically manage similar products. Conversely, DLA handles a varied line of products. This study determines whether product aggregation schemes have an impact on depot location decisions.

### 2. GEOGRAPHIC CUSTOMER AGGREGATION

DLA has over 45,000 customers. Recognition of each of these customers individually is impractical for any facility location model thus some customer aggregation is required.

A number of approaches has been used by analysts to aggregate customers including grouping customers by: geographic proximity, type of customer, type of export, or specific customer service requirements. Georeferencing approaches typically rely on Standard Metropolitan Statistical Areas, individual states, and postal zip code sections to aggregate customers.

Ballou [1993] uses a method that is particularly suited for this study whereby the 900 three-digit zip codes are used as a starting point. The pair of zip codes closest to one another are combined to form one cluster. This process is repeated until the desired number of clusters is attained. The center of the cluster is determined and this point becomes the demand location for that grouping of customers.

Errors arise as transportation costs are calculated based on distance measurements from the service center to the midpoint of a cluster region as opposed to an actual location.

Hillsman and Rhoda [1978] state that three types of errors are created as the result of this estimation:

- Cost error: cost errors results from measuring distance to the service center from the aggregated point instead of from the actual demand points;
- Error is created when the service center is located at the aggregated point in which case the distance from service center to demand is zero. This measurement underestimates the true transportation costs as the center is actually serving dispersed demand; and
- Errors are created when distances from aggregated demand points to service center are used to assign demand to the nearest center. In this situation some demand may be assigned to the wrong center.

Hillsman and Rhoda [1978] analyze the magnitude of these types of errors for contrived demand patterns. They conclude that demand aggregation causes distance measurement errors up to 8% for their contrived demand patterns and expect higher percentages for actual systems.

Extending Hillsman and Rhoda's research, Casillas [1987] conducts a study which determined the effects certain factors have on the facility location problem. Casillas defines the following two types of errors created as the result of demand aggregation:

- Cost-estimate error: the difference between the cost to service aggregated demand from the optimal service location and the true cost of servicing the unaggregated demand from that location;
- Optimality error: the effect of misallocating demand to service centers and the resultant mislocation of these centers based on the use of aggregated rather than unaggregated demand.

Varying "the level of aggregation, the location of aggregated demand points, and the number of service centers to be located," his study determines the effect these factors have on the objective function and the location of the service centers. Casillas' results show that the cost-estimate error is monotonically increasing with the number of source points and the level of aggregation. The results for the optimality error are not as conclusive in that there is no established pattern relating the optimality error with the number of source points and the level of aggregation. Casillas' conclusion is that in general customer aggregation does not have a significant effect on the location of service centers.

Current and Schilling [1987] also extend the research of Hillsman and Rhoda. They state that demand aggregation results in the loss of locational information which may result in suboptimal service center location. Their study devises a method of formulating the aggregated customer regions such that all but the third error (assigning demand to the nearest center) are eliminated. They compare their method to the traditional methods of forming clusters. Current and Schilling's study is accomplished on a distribution network consisting of 681 nodes aggregated into 30 and 70 demand units; five, seven, and nine source points; and uses four different sets of demand data. Using Casillas' definitions for optimality and cost errors, their study yields the following results:

- both optimality and costing errors increase monotonically with the number of sources; and

- both optimality and costing errors decrease as the number of demand clusters increase.

Research conducted by House and Jaimie [1981] on a distribution system consisting of seven market demand systems, eight warehouse networks, three shipment size groupings, and three consumer-oriented products reaches the following conclusions:

- as the number of markets increases, the outbound freight errors decreases;

- error in outbound transportation cost estimation can not be reasonably controlled with market systems of less than 100 aggregated customer points;

- shipment errors can be maintained within 2 - 3 percent with at least 150 markets; and

- as the number of distribution points increases relative to the number of markets transportation costing error increases.

Ballou [1991 and 1993] extends the research conducted by House and Jaimie [1981] examining the transportation costing error occurring in a distribution system. Ballou determines the effect the number of clusters, size of the clusters, and the number of source points have on the transportation costing error. Examining a distribution network consisting of source points ranging in number from 1 to 100, market clusters ranging in number from 50 to 900, and shipment sizes ranging from 500 pounds to a full truckload, Ballou [1993, p. 15] arrives at the following conclusions:

- the usual practice of using 100 to 200 clusters is not applicable to all problems;
- controlling the cluster size during cluster formation can significantly reduce transportation costing error;
- grouping customers by proximity is a reasonable way to form clusters and reduces transport costing error;
- costing error does not exceed 1.5 percent for carefully-formed clusters;
- as the number of sources increases the costing error also rises;
- costing errors are reduced with increased numbers of clusters; and
- costing errors increase as the number of facilities increases relative to the number of clusters.

Ballou [1993, p. 17] presents recommendations for total customer aggregations based on the number of source points, allowable error, and cluster size expressed as a percentage of total demand existing in the distribution network.

In summary, all literature suggests that as the number of customer groupings is reduced the area of the aggregated zone increases resulting in an increase in transportation costing errors. In the formulation of these customer groupings, these authors agree that:

- aggregation by proximity is a reasonable approach; and
- as the number of sources or depots increase relative to the number of customers, transportation costing error increases.

Ballou [1993] suggests that customer groupings in the 100 to 200 range is not applicable to all situations. For distribution networks with 25 source points (DLA's size), his study suggests that the number of customer groupings should be in the 300 to 500 range. This recommendation seems inapplicable to DLA because the top 100 three-digit zip codes account for approximately 84 percent of the material processed. The contention here is that a significant increase in transportation accuracy will not be gained through increasing the number of customer groupings much above 100. This study tests a range of customer groupings between 100 and 200.

### 3. SUPPLIER AGGREGATION

DLA has over 10,000 suppliers. Recognition of each of these suppliers individually is impractical for any facility location model thus some supplier aggregation is required.

Other than the procurement source aggregation scheme presented in the DODMDS study, there appears to be no other literature on supplier aggregation. The DODMDS study identifies the rationale for aggregating material sources as: "the large number and geographical dispersion of procurement sources; the dimensional limitations of the analytical models; and the need to make the data comprehensible to facilitate analysis" (DODMDS Vol III [1978] Section 4 p. 4.2). Because of the similar objectives, it seems reasonable to aggregate suppliers in the same fashion as customers, whereby a georeferencing system is used to identify major supplier zones and those remaining are aggregated with the major ones based on proximity. The specific approach used in the DODMDS study is addressed in subsequent sections.

## III AGGREGATION SCHEMES

This chapter discusses aggregation schemes for DLA's products, customers, and suppliers. Similarities and differences between aggregations in this thesis and the DODMDS study are highlighted.

### A. PRODUCT AGGREGATIONS

DLA manages over three million line items. Recognition of each of these products individually is impractical for any facility location model: Some product aggregation is required. The goal in this aggregation process is to develop categories which are sufficiently homogeneous for modeling purposes: Product groupings should have similar management, shipping, and handling characteristics. Because the DODMDS study is the only study of the literature reviewed which examines product aggregations, the DODMDS study provides the template for the schemes employed in this study.

Each item managed within the Federal supply system is assigned a national stock number (NSN) which uniquely identifies the item. The first four digits of the NSN is referred to as the Federal Supply Classification (FSC) and the last nine digits are the National Item Identification Number (NIIN). Figure 3.1 provides an example of the NSN for a steel wood screw. The four-digit FSC categorizes all material managed within the Federal system. The first two digits of the FSC identifies the major material groupings (in the example shown in Figure 3.1, FSC group 53 signifies that this item belongs to the Hardware and Abrasives group).

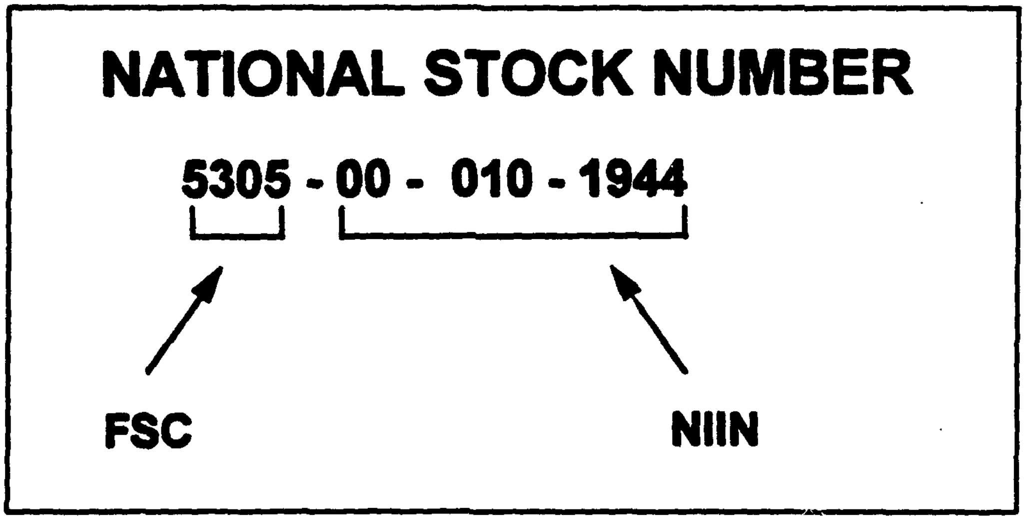


Figure 3.1: National Stock Number for a steel screw. The FSC 5305 expresses the group and class for the item: Group 53 signifies this item belongs to the Hardware and Abrasives Group and Class 05 signifies the item is a screw. The NIIN 00-010-1944 uniquely identifies this particular steel screw.

There are sixty-eight different groups managed by DLA which are listed in Appendix B. The second two digits represent the FSC class which provides a more detailed description of the type of material included in a group (Appendix B provides a detailed description of the classes available in FSC group 53 Hardware and Abrasives). The FSC forms a natural grouping mechanism since it "relates like items of supply and conversely separates unlike items of supply" (DLA H1 [1985]). Because of the large number of items and the diversity of material managed by DLA, the ease with which an aggregation scheme based on this system could be implemented, as well as the unique requirements of each service, aggregation strategies based on FSC are the most appealing approach.

The product aggregations developed are based on the Material Release Order files for fiscal year 1992 looking at the commodities listed in Table 3.1. These files are provided by the Defense Operations Research Office (DORO) and detailed material shipments for the specific commodities for the year.

Table 3.1: DLA provided the Material Release Order files for FY 1992 which lists all depot-to-customer shipments for FY 1992. All material in the Material Release Order files are labelled according to the following commodities.

| Commodity | Material Description |
|---|---|
| C | Construction |
| E | Electronics |
| G | General |
| I | Industrial |
| M | Medical |
| T | Textiles |

Because of difficulty obtaining and manipulating the required files, subsistence items (which accounted for 25 percent of total shipment weight in the DODMDS study) are excluded from this study. This exclusion is modeled by using a conservative estimate of capacity as discussed in the following chapter.

FSC offers an initial grouping of like items based mainly on management criteria. Shipping and handling characteristics are obtained by a statistical analysis of these groupings which shows the degree of homogeneity within FSC. The DODMDS study (DODMDS [1978] Vol III Section 4) subdivided all items within a FSC into fifteen intervals by unit weight, unit cube, and unit price. Statistical analysis of these groupings was accomplished to determine homogeneity within FSC. Four independent groups of analysts determined that like FSC's could be aggregated based on physical characteristics using the following ranking scheme:

- primary importance was placed on unit weight within FSC;
- secondary emphasis was placed on the issue weight for items within FSC; and
- the number of issues of individual items and the quantity of items issued were considered within FSC.

This aggregation process was performed iteratively where statistical analysis (calculation of mean and variance for the above characteristics) of the groupings determined whether aggregations were sufficiently homogeneous. The study derived 72-aggregate products which the DODMDS study concluded were sufficiently homogeneous for modeling purposes. These 72-aggregate products were further aggregated until 27-aggregate products resulted.

In addition to the DODMDS study, a number of other aggregation studies (See House and Jamie [1981]; Ballou [1991] and [1993]; Current and Schilling [1987]) have focused on shipment weight in transportation rate determination. As a result of conclusions derived from these studies and on DLA's evolution toward use of innovative depot-to-customer shipping modes, this thesis concentrates on weight characteristics to determine product aggregations.

A statistical analysis of the transaction files reveals the following:

- 91% of the total weight issued is composed of just 90 FSC's;
- 90% of the total issues is accounted for by just 90 FSC's; and
- 56 of the FSC's appear in both of these categories.

Because repairable components are not included, variability within FSC groupings is not as significant as that found in the DODMDS study. However, as Appendix C shows, significant variability still exists within FSC groupings. Further analysis reveals that 92% of the material shipments are less than fifty pounds. The material in the large weight categories is significantly different from the norm which helps explain the large variance found within each grouping.

The following four product aggregation schemes are developed and provided in detail in Appendix D:

- 67-aggregate products: Accomplished strictly by FSC product groupings. No distinction is made within product groupings between aviation and non-aviation related material.

- 44-aggregate products: The 67 aggregate products are further aggregated by grouping like items. A distinction is made within groupings between aviation and non-aviation related material.

- 29-aggregate products: The 44 aggregate products are further aggregated by grouping like items.

- 49-aggregate products: This approach is based on demand. Taking the top 75 FSC's by frequency of demand and total weight requisitioned, the FSC's which appear in both categories are the focus of a aggregate product and like items are grouped with these major FSC's. No distinction is made between aviation and non-aviation material within these aggregate products. Those products annotated with an asterisk in Appendix D7 represent aggregate products which are not centered around an item appearing on any of the top 75 list. Because this material is not similar to material found within any of these major groupings, separate aggregate products are created.

## B. CUSTOMER AGGREGATIONS

Customer aggregation is required to model the material flows from the distribution facilities to the more than 45,000 individual DLA customers. As the DODMDS study states: "Retaining the accuracy of demand location was most significant since the structure of a distribution system (distribution center location) is heavily influenced by the geographical location of the demand and sources of supply" (DODMDS Vol III [1978] Section 2 p 2.1).

The DODMDS study (DODMDS Vol III [1978] Section 2) identifies the major installations by total demand and aggregates remaining activities with these major installations based on proximity. This process is accomplished with three-digit zip codes and the Department of Defense Automatic Address Code (DODAAC), a six-digit code which identifies individual activities. DODMDS examined the material flows from depot to customer as well as material returns from customer to depot and created 205 aggregated groupings. Where feasible, uniformed service identity was retained.

This thesis uses the three-digit zip code aggregation facilities available in SAILS to aggregate customers. Aggregation schemes are developed based on the top 259 major American cities (as identified in SAILS, see Appendix E). These cities are initially identified as the major nodes. All customers outside these zones are aggregated with these major areas based on proximity. Demand for deploying and overseas activities is assigned to the two containerization facilities: Mechanicsburg, Pennsylvania on the East coast and Tracy, California on the West coast. Of the top 250 DLA customers (as identified by three-digit zip code and total weight received), 149 have three-digit zip codes corresponding directly to the three-digit zip codes of the 259 major American cities. Attempts to use this 259-customer model in SAILS have been unsuccessful: The model dimensions are too large to permit timely solutions. Using the transaction information from the 259-customer model, two customer aggregation schemes of 199 and 113 customers are developed.

Those cities which had less than 100,000 pounds (1 million pounds for the 113-customer aggregation) of shipment activity are deleted as major nodes. The total weight received by these cities amounts to 2.6 million pounds which accounts for less than one percent of total weight shipped (39 million pounds and less than 4 percent for the 113-customer aggregation). The cities included in both aggregation schemes are provided in Appendix E and a map of the cities comprising the 113-customer aggregation is provided in Figure 3.2.

An analysis of the transaction file shows that of the top 100 three-digit zip codes (according to total weight shipped), 66 three-digit zip codes directly correspond to the three-digit zip codes of the 113 major cities. These 66 three-digit zip codes account for 51 percent of total demand weight and 70 percent of the total requisitions.

## C. SUPPLIER AGGREGATIONS

Supplier aggregations are accomplished to facilitate dealing with the 10,000 material sources for the DLA distribution system. For procurement source aggregation, the DODMDS study (DODMDS Vol III [1978] Section 4) examines a number of alternate strategies and selected "the 80/20 rule" (80 percent of the procurement activity represented by 20 percent of the three-digit zip codes) as the preferred strategy: The DODMDS study identified the three-digit zip codes which provide 80 percent of the weight, 80 percent of the procurement dollar value, and 80 percent of the total transactions processed. Identified as nodes, these zip codes represent fifteen percent of the total United States zip codes

Figure 3.2: Cities comprising the 113-customer aggregation scheme. These aggregated locations are formed by taking the 259 major cities identified in SAILS and deleting those cities which account for less than 1 million pounds of demand activity (total weight received by these cities is 39 million pounds and less than four percent of total weight shipped).

and account for approximately ninety percent of the procurement activity in all three categories. The remaining sources identified by three-digit zip codes are grouped with these nodes based on proximity.

Initially this study chose to follow the same approach as the DODMDS study by identifying major supplier locations by three-digit zip codes and aggregating minor supplier zones with these primary locations. Because of difficulty with the procurement file supplied by DLA, accurate replenishment information is unavailable and therefore this study uses a supersource or single location as the sole procurement source. This location is a centralized location in Memphis, Tennessee three-digit zip code 375. The DODMDS study uses a supersource concept where the transportation rate from depot to customer is calculated as if each customer receives the aggregate product from all suppliers at the percentage of the total each supplier provides systemwide. This thesis calculates the transportation rates by aggregate product from the centralized location to each depot (*i.e.*, assuming all suppliers are located at the supersource).

### D. Transportation Mode Aggregations

The DOD transportation system moves material via the shipment modes identified in Table 3.2. This study acknowledges a requisition priority by retaining the mode structure. To facilitate data input into the SAILS model, the modes which experience limited use are aggregated with the

Table 3.2: This table provides the shipment modes, frequency, and percentage of total shipments for the DLA material shipments for FY 1992 as specified in the Material Release Order files. Obtained from DLA, these files provide all depot-to-customer material shipments for FY 1992.

| Description | Mode | Frequency | % of Total |
|---|---|---|---|
| Motor, truckload | A | 1992099 | 0.1262 |
| Motor, less truckload | B | 3568067 | 0.2261 |
| Van | C | 5 | 0.0000 |
| Driveaway | D | 75 | 0.0000 |
| Busline | E | 1 | 0.0000 |
| Military Airlift Command | F | 37571 | 0.0024 |
| Surface, parcel post | G | 953134 | 0.0604 |
| Air, parcel post | H | 624534 | 0.0396 |
| Govt truck | I | 147486 | 0.0093 |
| Small package carrier | J | 1741819 | 0.1104 |
| Rail, carload | K | 2877 | 0.0002 |
| Rail, less carload | L | 168 | 0.0000 |
| Freight forwarder | M | 7 | 0.0000 |
| LOGAIR | N | 17168 | 0.0011 |
| Organic Military Air | O | 594 | 0.0000 |
| Bill of Lading | P | 2452 | 0.0002 |
| Air freight/express | Q | 301755 | 0.0191 |
| Expedited air freight | R | 311 | 0.0000 |
| Scheduled truck | S | 96961 | 0.0061 |
| Air freight forwarder | T | 98742 | 0.0063 |
| QUICKTRANS | U | 11299 | 0.0007 |
| SEAVAN | V | 152730 | 0.0097 |
| Water, river, lake | W | 10 | 0.0000 |
| Bearer walk-thru | X | 5469 | 0.0003 |
| Intra-theater air lift | Y | 7549 | 0.0005 |
| Military Sealift Command | Z | 631 | 0.0000 |
| Govt watercraft | 2 | 80 | 0.0000 |
| Roll on\ Roll off | 3 | 120 | 0.0000 |
| Armed Forces Courier | 4 | 142 | 0.0000 |
| United Parcel Service | 5 | 5017392 | 0.3179 |
| Military Ordinary Mail | 6 | 1128 | 0.0001 |
| Express Mail | 7 | 29481 | 0.0019 |
| Pipeline | 8 | 56 | 0.0000 |
| Local Delivery | 9 | 701173 | 0.0444 |
| Missing/ erroneous | | 267551 | 0.0170 |

major modes as reflected in Table 3.3.

An analysis of the transaction files shows that 84 percent of the material is shipped using five mod · of shipment.

The SAILS model has Yellow Freight and United Parcel Service rate tables available to determine transportation rates. Additionally, user-defined rates can be incorporated into the model. This rate information is used to determine an average rate per hundredweight (CWT) for each aggregate product and depot-to-customer combination.

Because rate information for the transportation modes utilized by the DOD system are not readily available, this study chose to use the UPS and Yellow Freight rates available in SAILS to estimate these averages. When the eleven aggregated modes identified in Table 3.3 are used in the SAILS model, the results produce excessive SAILS execution times. These 11 modes are therefore consolidated into six shipment categories and a shipment profile is created based on an analysis of the transaction file. Table 3.4 details the percentage of usage for each of the six modes and their categories.

Table 3.3: Aggregation of limited-use shipment modes into the 11 major mode categories for initial input into the SAILS model.

| MAJOR MODE | EXPLANATION | AGGREGATED MODES | EXPLANATION |
|---|---|---|---|
| A | MOTOR, TL | C | VAN |
| | | D | DRIVEAWAY |
| | | P | TGBL |
| | | V | SEAVAN |
| | | S | SCHEDULED TRUCK SERVICE |
| B | MOTOR, LTL | 3 | ROLL ON/ ROLL OFF |
| K | RAIL, CARLOAD | M | FREIGHT FORWARDER |
| Q | AIR FREIGHT<br>AIR EXPRESS | L | RAIL, LESS THAN CARLOAD |
| | | R | EXPEDITED AIR FREIGHT |
| 9 | LOCAL DELIVERY | T | AIR FREIGHT FORWARDER |
| | | X | BEARER PICKUP |
| U | QUICKTRANS | I | GOVT TRUCK |
| | | O | ORGANIC MILITARY AIR |
| G | SURFACE PARCEL POST | N | LOGAIR |
| | | 6 | MILITARY ORDINARY MAIL |
| | | E | BUSLINE |
| | | J | SMALL PACKAGE CARRIER |
| H | AIR PARCEL POST<br>1ST CLASS MAIL | 5 | UPS |
| | | 7 | EXPRESS MAIL |
| F | MILITARY AIRLIFT COMMAND | | |
| Z | MILITARY SEALIFT COMMAND | | |
| $ | MISC | 4 | COURIER |
| | | 8 | PIPELINE |
| | | Y | INTRA THEATER AIRLIFT |
| | | W | RIVER, LAKE |
| | | 2 | GOVT WATERCRAFT |
| | | | MISSING & ERRONEOUS ENTRIES |

Table 3.4: This table details the six alternate aggregated transportation modes used with model runs, the SAILS rate category used for each of these modes, and the usage percentages. This information is used by SAILS to calculate an average rate per hundredweight for each depot-to-customer link.

| Mode | Rate Category | Percent |
|---|---|---|
| Truck Load | 10000 TO 20000 lbs | 32.95 |
| Less Than Truckload | 0 to 5000 lbs | 42.94 |
| Air Freight/Air Express | UPS Next Day Air | 2.72 |
| Local Delivery/Rail | 400k to 999k | 12.07 |
| Surface Parcel Post | UPS Surface Parcel Post | 8.38 |
| First Class Mail MAC/QUICKTRANS | UPS Second Day Air | 0.94 |

## E. DEPOT AGGREGATIONS

This study includes the major depots examined by the DODMDS study with the addition of Naval Supply Centers in Charleston, Pensacola, and Puget Sound. In 1992, DLA used a number of secondary storage facilities which were subsequently closed. The secondary sites shown in Table 3.5 have been aggregated herein with the major depots based on proximity. With the exception of those depots identified for closure in 1993 under BRAC (Charleston, Oakland, and Pensacola) (BRAC [1993]), the major depots identified in Table 3.5 are the remaining facilities subject to the next base closure examination. Collocated depots (such as Tracy and Sharpe) are

**Table 3.5:** This table provides a listing of the major depots and the aggregation process this study uses to combine the secondary storage sites with the major depots. Depots that are annotated with an asterisk are slated for closure under BRAC 1993.

| DEPOT CODE | MAJOR DEPOT | SEC DEPOT CODES | SECONDARY DEPOTS |
|---|---|---|---|
| [illegible] | SHARPE ARMY DEP LATHROP, CA 95331 | [illegible] | SHARPE ARMY DEPOT LATHROP, CA 95331 |
| [illegible] | [illegible] TRACY, CA 95376 | [illegible] | [illegible] |
| [illegible] | MEMPHIS, TN 38114 | [illegible] | [illegible] |
| [illegible] | [illegible] MECHANICSBURG 17055 | [illegible] | NEW CUMBERLAND ARMY DEPOT, PA 17070<br>[illegible] ARMY DEPOT (EUROPE)<br>[illegible] |
| [illegible] | COLUMBUS 43216 | [illegible] | LEXINGTON, KY 40511<br>ROCK ISLAND ARSENAL, IL 61299<br>[illegible]<br>SAVANNA ARMY DEPOT, IL 61074<br>[illegible] GREAT LAKES, IL [illegible]<br>[illegible] INDIANAPOLIS, IN 46219<br>LOUISVILLE KY 40214<br>CRANE, IN 47522 |
| [illegible] | [illegible] OGDEN 84407 | | |
| [illegible] | TOBYHANNA, PA 18466 | [illegible] | TOBYHANNA ARMY DEPOT, PA [illegible]<br>SENECA ARMY DEPOT ROMULUS, NY 14541<br>[illegible] PORTSMOUTH, NH [illegible]<br>[illegible] NEW LONDON GROTON, CT 06340<br>[illegible]<br>[illegible] |
| [illegible] | SAN ANTONIO, TX 78241 | [illegible] | [illegible] |
| [illegible] | RICHMOND, VA 23297 | [illegible] | [illegible] |
| [illegible]* | OAKLAND, CA 94625 | [illegible] | [illegible] |
| [illegible] | MCCLELLAN AFB SACRAMENTO, CA | [illegible] | SACRAMENTO ARMY DEPOT CA 95813 |
| [illegible] | SAN DIEGO, CA 92132 | [illegible] | [illegible] |
| [illegible] | BARSTOW CA 92311 | [illegible] | [illegible] EL TORO SANTA ANA [illegible] CA [illegible] |
| [illegible] | JACKSONVILLE, FLA 32212 | [illegible] | [illegible] |
| [illegible] | NORFOLK, VA 23512 | [illegible] | [illegible]<br>YORKTOWN, VA 23691<br>[illegible] NORFOLK, VA 23512 |
| [illegible]* | CHARLESTON, SC 29411 | [illegible] | CHARLESTON, SC 29408 |
| [illegible] | ANNISTON ARMY DEPOT AL 36201 | [illegible] | REDSTONE ARSENAL, AL 35898 |
| [illegible] | ALBANY, GA 31704 | [illegible] | ALBANY, GA 31705<br>ALBANY, GA 31705 |
| [illegible] | PUGET-BREMERTON WA 98314 | [illegible] | ARMY DEPOT HERMISTON, OR [illegible]<br>TRIDENT [illegible] WA [illegible]<br>[illegible] WA [illegible]<br>[illegible] OAK HARBOR, WA 98277 |
| [illegible] | LETTERKENNY ARMY DEPOT, PA 17201 | | |
| [illegible] | RED RIVER ARMY DEPOT TEXARKANA, TX 75507 | [illegible] | RED RIVER ARMY DEPOT TEXARKANA, TX 75507 |
| [illegible] | HILL AFB, UT 84056 | [illegible] | PUEBLO, CO 81001<br>TOOELE ARMY DEPOT, UT 84074 |
| [illegible] | TINKER AFB OKLAHOMA CITY, OK 73145 | [illegible] | ATCHISON, KS 66002 |
| [illegible] | [illegible] ROBINS AFB GA 31098 | | |
| [illegible]* | NSC PENSACOLA, FL 32508 | | |
| [illegible] | MCAS CHERRY PT, NC 28533 | | |
| [illegible] | NEW CUMBERLAND PA 17070 | | |
| [illegible] | ARMY DEPOT CORPUS CHRISTI, TX 78419 | [illegible] | ARMY DEPOT CORPUS CHRISTI, TX 78419 |

maintained as separate entities. Figure 3.3 provides the relative locations of the 28 major depots.

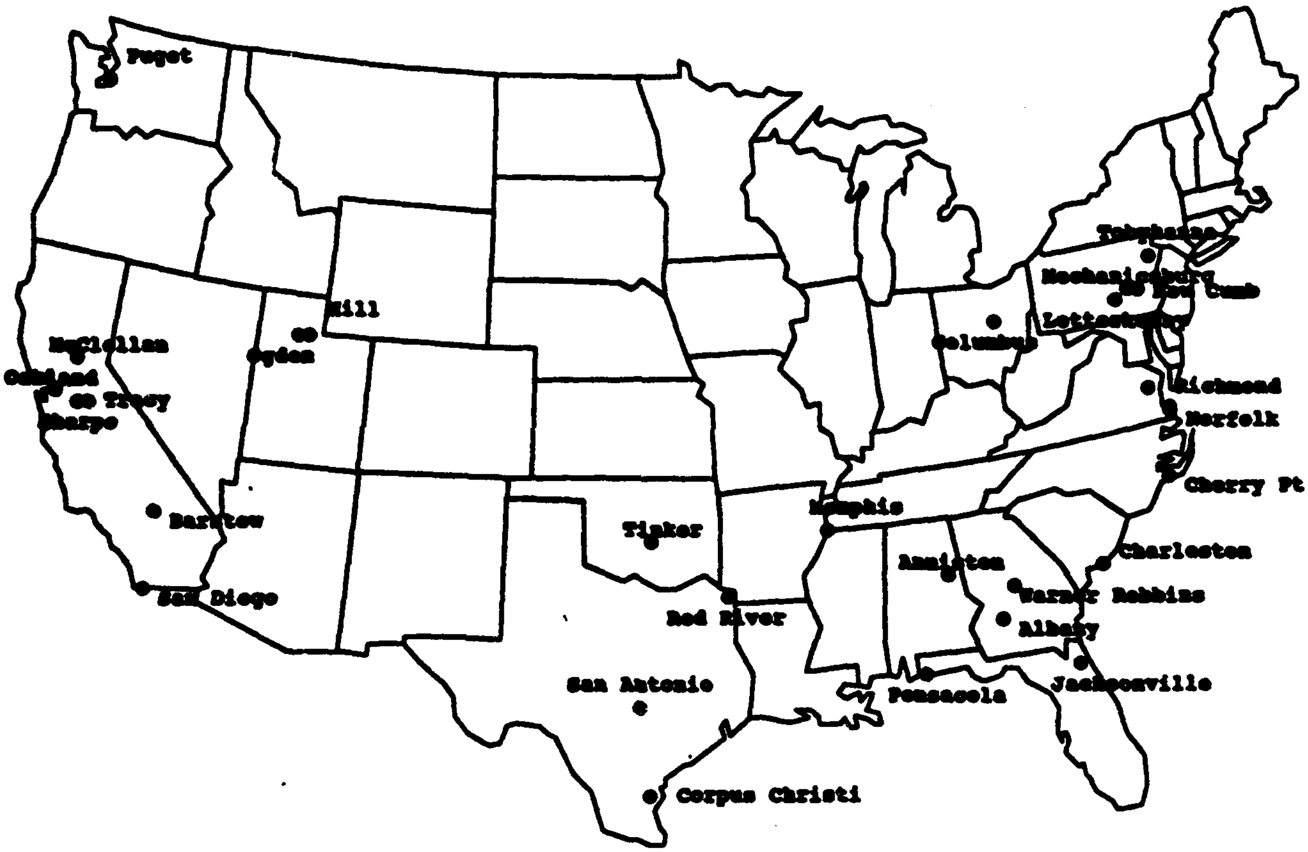


Figure 3.3: The relative location of the 28 major depots where secondary storage facilities are aggregated with the major depots based on location proximity.

# IV. COMPUTATIONAL EXPERIENCE

This chapter contains detailed information on test data, scenarios tested, and solutions obtained using SAILS.

## A. DATABASE

### 1. TRANSACTION FILE

The Material Release Order files for fiscal year 1992 are obtained from the Defense Operations Research Office (DORO) in Richmond, Virginia. Using the SAS software package (SAS Institute Inc [1990]) on an AMDAHL 5995-700A mainframe, data from the Material Release Order files are summarized and manipulated into a transaction file (which is customer demand data) in the correct format for SAILS model input. Initially, the Material Release Order file is comprised of approximately 17 million records. After extracting those requisitions created during the base year and removing erroneous records, a transaction file comprised of 15.8 million material shipments and totalling 1.032 billion pounds is created.

Due to the size of this transaction file, product aggregation is accomplished outside the SAILS model. Four separate transaction files representing each of the product aggregation schemes detailed in Chapter 3 is created for input into SAILS. These files are formatted in the outbound transaction file format (TF4)(INSIGHT Inc., SAILS Users Manual [1993]) required for input into the SAILS model as depicted in Table 4.1. To limit the size of the input file herein, shipment date information is not retained. As a result, all transactions for the period examined are assumed to be processed on julian date 92001. This process can underestimate total transportation costs as the model develops transportation rates based on the shipment profile depicted in Table 3.4.

Table 4.1: SAILS Outbound Transaction File Data Elements. Four separate transaction files representing each of the alternate product aggregation schemes is created for input into SAILS.

| Data Element | DESCRIPTION |
|---|---|
| Customer Class | shipment mode information |
| Customer Aggregation Code | three-digit customer zip code |
| Stock Code | aggregate product number |
| Quantity | total number of transactions |
| Original DC code | 3-character Depot Code |
| Julian Date | 92001 (total annual demand) |
| Extended Weight | total weight shipped for that aggregate product, depot-to-customer link |

The transaction file is sorted and summarized by aggregate product number, three-digit customer zip code, depot, and shipment mode. The total weight shipped for each aggregate product and depot-to-customer link is calculated by multiplying the total number of transactions for that link by the mean extended weight (an average calculated by multiplying requisition quantity times unit weight). File sizes for the four transaction files are provided in Table 4.2.

Table 4.2: Four different Outbound Transaction Files are generated based on the alternate product aggregation schemes employed. This table details the total number of transactions and file sizes for each of these files.

| Product Aggregation Scheme | Total # of Aggregate Transactions | File Size (megabytes) |
|---|---|---|
| "29" | 309,300 | 36.2 |
| "44" | 360,497 | 42.2 |
| "49" | 464,955 | 54.4 |
| "67" | 388,001 | 45.4 |

## 2. FACILITIES

Cost and throughput capacity information for the distribution depots identified in previous sections are developed based on information provided by DORO and DLA Headquarters. Estimates of depot fixed and variable costs are based on information provided by DORO and are listed in Table 4.3. This information represents fiscal year 1989 estimates of depot costs. Since these figures are estimates, no attempt to convert these costs to fiscal year 1992 is considered. Fixed costs are explicitly expressed and are input into the model to the nearest hundred thousand dollars. Cost information for Marine Corps facilities at Barstow, Albany, and Cherry Point are not provided. Fixed costs for these facilities are estimated at ten million dollars.

Variable costs provided by DORO are in unit cost per transaction. Because all transactions in the SAILS model are based on CWT, conversion is required. This study finds an estimated average weight per transaction and multiplies this figure by the number of transactions processed by each depot as a rough estimate of total weight processed by the depot. The variable cost per CWT is then determined by dividing the total variable cost for that depot by the total CWT processed. Both depot fixed and variable costs are provided in Table 4.3.

Depot throughput capacity is calculated based on estimates provided by DLA headquarters. These estimates are based on the number of transactions a facility could handle in a day at peak capacity. Since all model calculations are based on CWT, conversion to the amount of CWT each facility could handle is required. Additionally, these calculations need to be annualized. The conversion process is similar to the variable cost calculation where an average weight per transaction is estimated. This average is multiplied by the maximum number of transactions the facility could handle daily and a conservative estimate of the number of work days in a year (250): Only 250/365 (68 percent). The resulting throughput capacity is shown in Table 4.3. Because of the close proximity of Mechanicsburg and New Cumberland, DLA Headquarters expresses their throughput capacity as one total which this study splits in half and reports for each facility separately. This situation also exists for Sharpe and Tracy on the West coast.

Table 4.3: The depot fixed and variable costs and throughput for FY 92 used in the *SAILS* model.

| Depot | Fixed Cost (000) | Variable Cost per CWT | Model Throughput (million pounds) |
|---|---|---|---|
| Columbus | 17900 | 10.7775 | 150 |
| Memphis | 31200 | 11.9834 | 310 |
| Mechanicsburg | 24700 | 10.1335 | 510 |
| Tracy | 30200 | 11.8671 | 290 |
| Ogden | 18200 | 2.5938 | 380 |
| Richmond | 21200 | 10.6428 | 230 |
| Letterkenny | 15000 | 43.16496 | 50 |
| New Cumberland | 22700 | 26.8313 | 510 |
| Anniston | 6000 | 45.666 | 40 |
| Sharpe | 14600 | 39.0369 | 290 |
| Tobyhanna | 5400 | 45.0523 | 37 |
| Red River | 17900 | 36.2445 | 140 |
| Corpus Christi | 2400 | 21.7966 | 50 |
| Oakland | 19000 | 12.8446 | 67 |
| San Diego | 15100 | 9.1073 | 160 |
| Puget Sound | 6900 | 12.3212 | 60 |
| Norfolk | 28700 | 13.325 | 210 |
| Charleston | 6200 | 9.8786 | 170 |
| Jacksonville | 6900 | 9.7052 | 64 |
| Pensacola | 6000 | 9.2826 | 60 |
| McClellan AFB | 13000 | 30.3438 | 97 |
| San Antonio | 15200 | 27.1729 | 150 |
| Tinker AFB | 16500 | 21.7179 | 70 |
| Hill AFB | 9800 | 22.0196 | 170 |
| Warner Robbins | 13700 | 24.8766 | 140 |
| Cherry Point | 10000 | 10.00 | 40 |
| Barstow | 10000 | 10.00 | 17 |
| Albany | 10000 | 10.00 | 16 |

## B. RUN DESCRIPTIONS

The SAILS model is run under Windows NT on a 586 66MHz personal computer with 261 megabytes of extended memory and one gigabyte of disk space. With the smaller models (less than 49 products and 113 customers), SAILS requires about 125 megabytes of extended memory to operate. The maximum level of extended memory required is 225 megabytes occurring with 199 customer aggregations.

The approach here is to systematically reduce throughput capacity across all depots to examine the effects these reductions have on total costs and the recommended depot closures. Five separate versions of the model are run for each of the aggregation schemes at full depot throughput capacity, and at 90%, 80%, 50% , and 30% of that capacity. Additionally, the throughput capacity violation penalty (available in the SAILS model) is maintained at a high level to ensure no capacity violations within a depot.

Recall that DLA subsistence items which account for approximately 25 percent of total demand weight are not directly modeled in this thesis. The subsistence demand weight is indirectly modeled by using a conservative estimate of depot throughput capacity where a 250 day work year is used instead of a 365 day work year (possible during peak periods).

Runs are accomplished under the four alternate product aggregation schemes, with 113-customer aggregations, and at the five alternate depot throughput capacity levels. To determine the effects of a different customer aggregations, additional runs are accomplished with a 199-customer aggregation, 29-aggregate products scheme and at five alternate depot throughput capacity levels.

Within SAILS, the ability exists to specify a maximum distance between depot and customer. For all runs with the exception of one test case, this distance is set at the default setting of 7500 miles - essentially unrestricted.

## C. RESULTS

Table 4.4 provides the number of variables and constraints for the different models. Intuitively, it would be reasonable for the number of variables to increase as the number of aggregate products increases, but this is not always the case. Recall that the 67-aggregate product scheme is created by aggregating products by the two-digit product group. The 44- and 29-aggregate product schemes are simply further aggregations of the 67-aggregate product scheme. Table 4.4 shows that different aggregation schemes for the 44- and 29-aggregate product schemes create different depot-to-customer grouping combinations. Recall that the approach is slightly different for the 49-aggregate product scheme: Aggregate products are created around those FSC's which experience significant demand. This accounts for the higher number of variables. By expanding the number of customer aggregations, both the number of constraints and variables increases dramatically as expected.

Table 4.4: Five versions of a model depicting the DLA distribution system are created in SAILS based on different product and customer aggregation schemes. This table describes the number of constraints and variables for each of these SAILS models. By expanding the number of customer aggregations, both the number of constraints and variables increases dramatically as expected.

| Aggregate Products | Customer Aggregations | Constraints | Variables |
|---|---|---|---|
| 29 | 113 | 3,308 | 78,971 |
| 44 | 113 | 3,308 | 74,708 |
| 49 | 113 | 3,308 | 80,132 |
| 67 | 113 | 3,308 | 67,609 |
| 29 | 199 | 5,802 | 132,777 |

The SAILS model develops an optimal strategic distribution network (*i.e.*, determines optimal depot locations for a network operating over a long time-frame) as opposed to a tactical or operational plan. As part of this strategic modeling, SAILS sole-sources aggregate products to a specific depot. SAILS creates two reports to help show the effect of sole-sourcing. The *accounting baseline* reports the tactical statistics on actual day-to-day operations and the *model* *baseline* reports the same statistics prior to optimization where aggregate products are sole-sourced to a specific depot.

Table 4.5 summarizes *accounting baseline* (actual depot-to-customer shipments by "product bundle" - an aggregate product before sole-sourcing), *model baseline* (depot-to-customer shipments after sole-sourcing or assignment of an aggregated product group to a specific depot) and the optimal solution for the 29-aggregate products, 113-customer aggregation, full-capacity model. Comparisons between the baseline and depot capacities reveal that Albany is the only depot which exceeds calculated capacity (this deviation is only 29,000 CWT; a minimal amount in comparison to total weight shipped). Test runs show that increasing Albany's throughput capacity by this amount has no effect on solutions.

Figures 4.1 and 4.2 graphically depict depot throughput capacity, *accounting baseline*, and *model baseline* for the 29-aggregate products, 113-customer aggregation, full capacity model. Apparent in these graphs and in Table 4.5 is the fact that the depots are not operating at or even near full capacity.

Table 4.5: FY 1992 Transaction Files show by depot the accounting baseline (actual depot-to-customer weight shipped), *the model baseline* (depot-to-customer shipment weight after the aggregate product has been sole-sourced to a specific depot), and the optimal solution for the 29-aggregate product, 113-customer aggregation SAILS model.

| Depots | Depot Code | Model Throughput (cwt) | Model Baseline Weight (cwt) | Accounting Baseline Weight (cwt) | Optimal Solution Weight (cwt) |
|---|---|---|---|---|---|
| Sharpe AD | AQ | 2900000 | 45352 | 141868 | 0 |
| San Joaq/ Tracy | SB | 2900000 | 2334277 | 1677995 | 0 |
| Memphis | SM | 3100000 | 2038131 | 2292073 | 0 |
| Mech | SA | 5100000 | 1548063 | 1574424 | 4521065 |
| Columbus | SC | 1500000 | 684681 | 647122 | 0 |
| Ogden | SU | 3800000 | 986238 | 1228332 | 3778513 |
| Tobyhanna | BY | 370000 | 98 | 3844 | 0 |
| San Antonio | FP | 1500000 | 8775 | 31988 | 0 |
| Richmond | SR | 2300000 | 1637899 | 1311861 | 0 |
| Oakland | NO | 670000 | 312544 | 262013 | 0 |
| McClellan AFB | FF | 970000 | 0 | 5798 | 0 |
| San Diego | ND | 1600000 | 51429 | 64716 | 0 |
| Barstow | MV | 170000 | 11731 | 13104 | 0 |
| Jacksonville | NB | 640000 | 137365 | 115344 | 639065 |
| Norfolk | NN | 2100000 | 4294 | 20577 | 0 |
| Charleston | NR | 1700000 | 0 | 8163 | 0 |
| Anniston AD | BA | 400000 | 33 | 9024 | 0 |
| Albany | MA | 160000 | 220204 | 189139 | 0 |
| Puget-Bremerton | NU | 600000 | 52 | 13343 | 422899 |
| Letterkenny | BK | 500000 | 16949 | 21409 | 0 |
| Red River | BR | 1400000 | 55663 | 112362 | 0 |
| Hill AFB | FG | 1700000 | 4275 | 16279 | 562752 |
| Tinker AFB | FH | 700000 | 41933 | 35435 | 0 |
| Warner Robbins AFB | FL | 1400000 | 202 | 5893 | 0 |
| NSC Pensacola | NA | 600000 | 0 | 1691 | 0 |
| MCS Cherry Pt | PT | 400000 | 1910 | 2273 | 0 |
| New Cumberland | SN | 5100000 | 179007 | 314294 | 0 |
| Corpus Christi | B5 | 500000 | 39 | 782 | 397003 |
| Dummy Dist | | 0 | 0 | 0 | 0 |

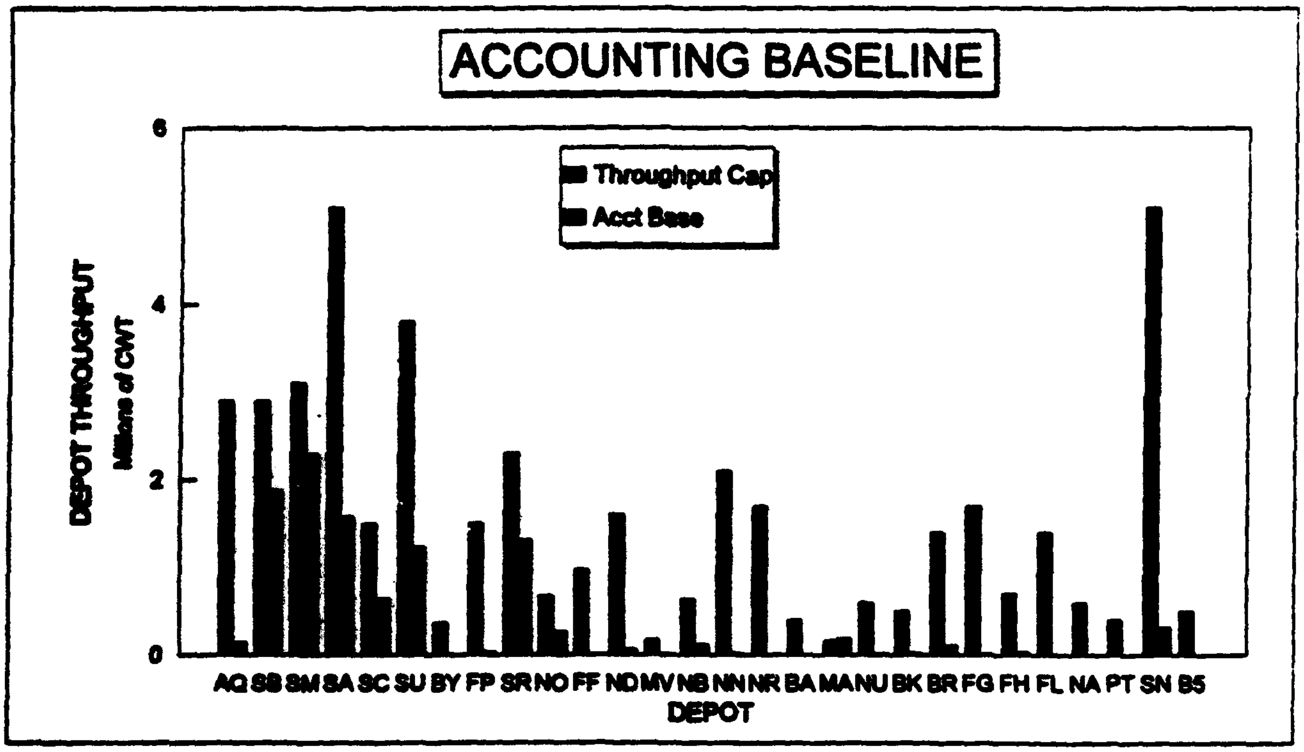


Figure 4.1: FY 92 Comparison of the depot throughput capacity to actual throughput for the 29-aggregate product, 113-customer aggregation SAILS model. For example, Mechanicsburg (depot code SA) has an estimated throughput capacity over five million CWT but has actual throughput of less than two million CWT.

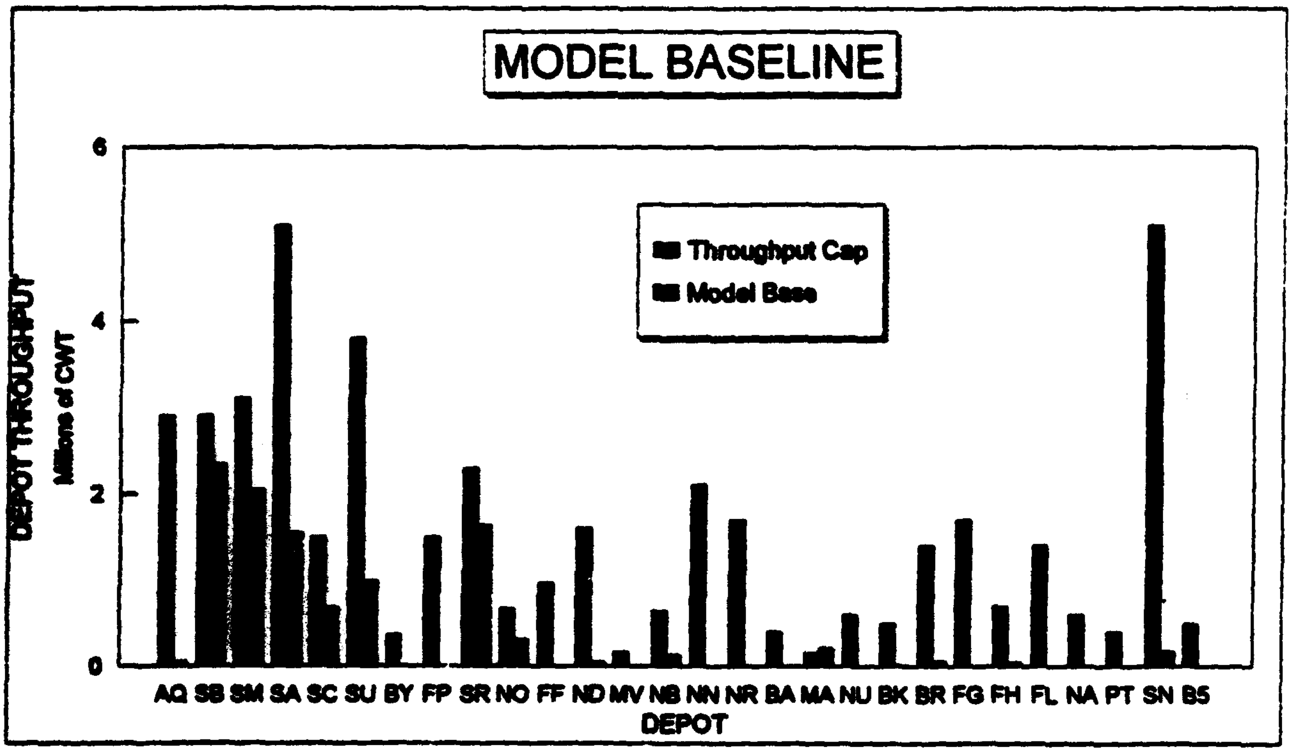


Figure 4.2: Comparison of the depot throughput capacity to baseline model throughput for the 29-aggregate product, 113-customer aggregation *SAILS* model. When compared to the accounting baseline this shows the minimal effect sole-sourcing aggregate products has on individual depot capacity utilization.

As depot throughput capacities are reduced, this restriction should increase total costs. Figure 4.3 shows that, as expected, throughput capacity is reduced and total operating costs increase.

Table 4.6 summarizes costs for accounting baseline, model baseline, and the optimal solution. Significant cost savings are suggested: Modeled savings total over 300 million dollars.

Figure 4.3: Depicts the total operating costs for each of the five depot throughput capacities examined for the 29-aggregate products, 113-customer aggregation SAILS model.

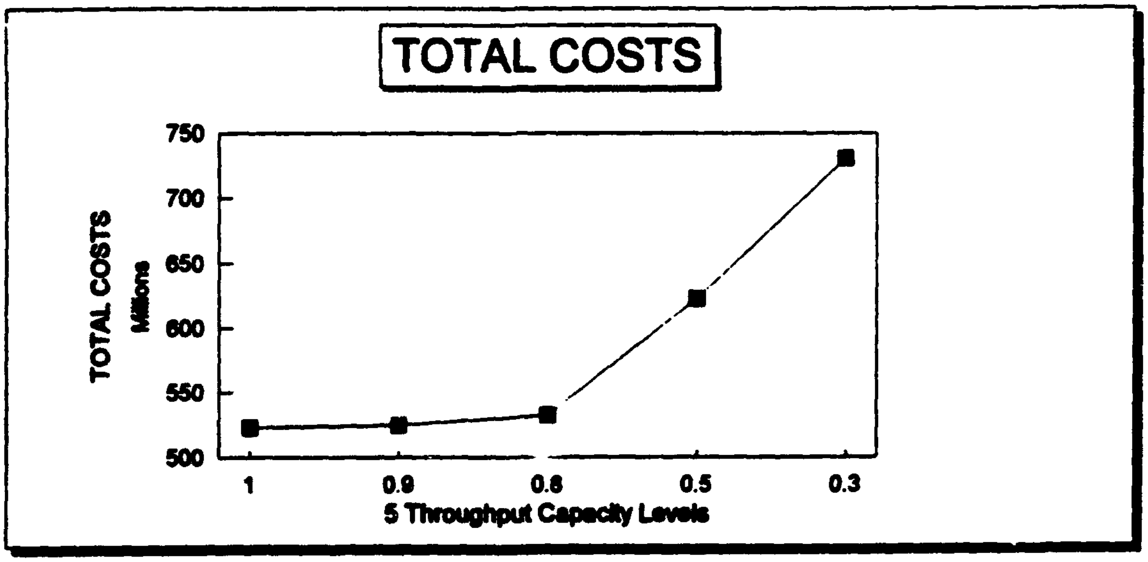


Table 4.6: Cost Summarization for the 29-aggregate products, 113-customer aggregation SAILS model.

| Costs | Accounting Baseline | Model Baseline | Optimal |
|---|---|---|---|
| Fixed Costs | 418,200 | 391,000 | 68,700 |
| Variable Costs | 119,550 | 114,777 | 87,990 |
| Capacity Viol | 291,385 | 621,511 | |
| Replenishment | 10,092 | 10,756 | 12,470 |
| Outbound | 408,202 | 342,182 | 353,999 |
| Total (excluding penalty) | 956,044 | 858,715 | 523,159 |

For purposes of this study, the solution gap (the difference between a bound on the best possible solutions and the best solution obtained) is three percent or less of total costs. A detailed discussion of each model run is presented in the following paragraphs.

Results of the runs accomplished at full depot capacity are presented in Table 4.7. The solutions for the 29-, 44-, and 49-aggregate product schemes are indistinguishable: Total costs differ by only $30,000 between the different versions and the recommended depot closures are identical. The total costs for the 67-aggregate products are slightly higher, but within the required solution gap. More importantly, the recommended depot openings differ by one facility. Unlike alternate solutions, this solution recommends that San Diego remain open instead of Puget. Table 4.7 shows that if the common configuration from the 29-, 44-, and 49-aggregate products model is fixed in the 67-aggregate product model, a smaller solution gap results. This shows that a number of alternate DLA depot configuracions are realizable, all with comparable cost savings.

Table 4.8 presents results obtained when all depots are only allowed 90 percent of their estimated throughput capacity. As expected, total costs for tne 29-aggregate product model are higher than at full capacity.

Table 4.7: Solutions to the full capacity model with 113-customer aggregation. Alternate product aggregations produce the same depot closure decisions. The solution gap represents the difference between a bound on the best possible solution and the best solution obtained.

| Aggregate Products | Remarks | Run Times (min) | Total Costs (000) | Soln Gap | Number of Open Depots | Open Depots |
|---|---|---|---|---|---|---|
| 29 | | 59 | 523,159 | 10 | 6 | Mech/ Ogden/ Jax/ Puget/ Hill/ Corpus |
| 44 | | 27 | 523,191 | 5.225 | 6 | Mech/ Ogden/ Jax/ Puget/ Hill/ Corpus |
| 49 | | 35 | 523,161 | 10 | 6 | Mech/ Ogden/ Jax/ Puget/ Hill/ Corpus |
| 67 | | 44 | 525,329 | 10 | 6 | Mech/ Ogden/ San Diego/Jax/ Hill/ Corpus |
| 67 | Locked all depots closed except 6 open in the 29-aggregate products solution | 25 | 523,223 | 7.894 | 6 | Mech/ Ogden/ Jax/ Puget/ Hill/ Corpus |

Table 4.8: Solutions to the 90 percent capacity model with 113-customer aggregation. Alternate product aggregations produce the same depots closure decisions. Solution gap represents the difference between a bound on the best possible solution and the best solution obtained.

| Aggregate Products | Remarks | Run Times (min) | Total Costs (000) | Soln Gap | Number of Open Depots | Open Depots |
|---|---|---|---|---|---|---|
| 29 | | 57 | 524,982 | 11 | 5 | Mech/ Ogden/ San Diego Jax/ Hill |
| 29 | Locked open depot solution from the full capacity run | 31 | 525,985 | 12 | 7 | Mech/ Ogden/ San Diego Jax/ Puget/ Hill/ Corpus |
| 44 | | 35 | 525,051 | 1.256 | 5 | Mech/ Ogden/ San Diego Jax/ Hill |
| 49 | | 57 | 526,512 | 2.71466 | 5 | Mech/ Ogden/ San Diego Jax/ Hill |
| 67 | | 37 | 528,018 | 10 | 6 | Mech/ Ogden/ San Diego Jax/ Puget/ Hill |
| 67 | Locked all depots closed except 5 open in the 29-aggregate product solution | 28 | 524,864 | 8.886 | 5 | Mech/ Ogden/ San Diego Jax/ Hill |

A reduction in the number of open depots is apparent when comparing the full and 90 percent capacity versions: San Diego, a larger depot, replaces both Puget and Corpus Christi. Because total throughput capacity available at both Puget and Corpus Christi is less than that available at San Diego, this alternative is a viable one.

When the solution for recommended depot closures from the full capacity run is established in the 90 percent capacity version, both the recommended number of open depots and total costs increase as expected. However, both solutions are within the required solution gap reinforcing the idea that a number of alternate solutions is possible.

In the 90 percent capacity model, the recommended depot configuration for 67-aggregate product version differs from the others. In this version, Puget remains open which results in six total depots remaining open as opposed to five from the other versions. As the depot configuration from the others is established in the 67-aggregate product model, total costs and the solution gap are less than the previous version.

With 80 percent capacity, total operating costs are expected to increase. Table 4.9 shows that all versions result in these cost increases and that depot configurations are varied among the different models: 29- and 67-aggregate product versions agree with low solution gaps and the 44- and 49-aggregate product versions agree with slightly higher solution gaps. When the depot configuration from the 29-

aggregate product version is fixed in the 44- and 49-aggregate product models, solution gaps increase. Solution gaps from these subsequent runs are still within study requirements and therefore represent viable alternate solutions.

At 50 percent capacity, the restricted models become much more difficult to solve and the results vary. Solution gaps are higher than three percent of total costs and attempts to reduce them result in run times in excess of four hours. Furthermore, attempts with all models to "lock in" the 29-aggregate product solution for comparison purposes also result in long run times. The results provided in Table 4.10 reflect solutions that are within solution gaps of less than five percent.

Table 4.9: Alternate solutions to the 80 percent capacity model with 113-customer aggregation. Alternate product aggregations produce the same depot closure decisions.

| Aggregate Products | Remarks | Run Times (min) | Total Costs (000) | Soln Gap | Number of Open Depots | Open Depots |
|---|---|---|---|---|---|---|
| 29 | | 129 | 532,002 | 2.564 | 7 | Mech/ Ogden/ San Diego Jax/ Puget/ Hill/ Corpus |
| 44 | | 82 | 532,495 | 10 | 5 | San Joaq/ Mech/ Ogden Jax/ Corpus |
| 44 | Locked open 7 depots from the 29-aggregate products solution | 46 | 535,251 | 12.756 | 7 | Mech/ Ogden/ San Diego Jax/ Puget/ Hill/ Corpus |
| 49 | | 73 | 535,278 | 10 | 5 | San Joaq/ Mech/ Ogden Jax/ Puget |
| 49 | Locked open 7 depots from the 29-aggregate products solution | 30 | 535,347 | 12.94053 | 7 | Mech/ Ogden/ San Diego Jax/ Puget/ Hill/ Corpus |
| 67 | | 80 | 531,874 | 2.46 | 7 | Mech/ Ogden/ San Diego Jax/ Puget/ Hill/ Corpus |

Table 4.10: Solutions to 50 percent capacity model with 113-customer aggregation. Run times in excess of four hours are experienced when attempting to remain within the three percent solution gap. Although depot closure recommendations are not uniform among all models, six common depots are recommended to remain open.

| Aggregate Products | Run Times (min) | Total Costs (000) | Soln Gap | Number of Open Depots | Open Depots |
|---|---|---|---|---|---|
| 29 | 54 | 622,512 | 28 | 9 | San Joaq/ Memphis/ Mech Columbus/ Ogden/ San Antonio Richmond/ San Diego/ Barstow |
| 44 | 41 | 601,640 | 20 | 9 | San Joaq/ Memphis/ Mech Columbus/ Ogden/ Richmond San Diego/ Jax/ Puget |
| 49 | 59 | 611,568 | 25 | 11 | San Joaq/ Memphis/ Mech Ogden/ Richmond San Diego/ Barstow/ Jax/ Puget Hill/ Cherry Pt |
| 67 | 37 | 638,576 | 30 | 12 | San Joaq/ Memphis/ Mech Columbus/ Ogden/ Richmond San Diego/ Jax/ Albany Puget/ Tinker/ Cherry Pt |

Run times for the 30 percent capacity models are excessive. Results are obtained for the 44-, 49-, and 67-aggregate product models, but not within the required solution gap (three percent of total costs). As shown in Table 4.11, a successful run is attained for the 29-aggregate product version, but requires over eight hours of run time. An interesting situation occurs at the 30 percent capacity levels for all versions of the model: Hill is forced into the solution. Regardless of the throughput violation penalty setting, Hill consistently exceeds capacity by 53,000 CWT. Therefore, to achieve any results, the throughput capacity for Hill is increased by 53,000 CWT.

Table 4.11. Solutions to the 30 percent capacity model with 113-customer aggregation. Run times in excess of eight hours are experienced when attempting to remain within the three percent solution gap. All aggregations report some depot closures and four common depot closures are recommended regardless of which model is used.

| Aggregate Products | Run Times (min) | Total Costs (000) | Soln Gap | Number of Open Depots | Closed Depots |
|---|---|---|---|---|---|
| 29 | 511 | 730,515 | 10.12137 | 16 | Tobyhanna / McClellan / Barstow Norfolk / Anniston / Albany / Letterkenny Tinker / Cherry Point |
| 44 | 28 | 792,601 | 50 | 19 | Tobyhanna / McClellan / Anniston Letterkenny / Red River / Corpus Christi |
| 49 | 68 | 792,845 | 45 | 19 | Tobyhanna / McClellan / Anniston Letterkenny / Red River / Corpus Christi |
| 67 | 29 | 777,775 | 50 | 17 | Tobyhanna / McClellan / Anniston Albany / Letterkenny / Red River / Cherry Point / Corpus Christi |

A 29-aggregate product, 199-customer aggregation model has been created to determine the effect additional customer zones have on total costs. Recall that numerous studies report a decrease in transportation costing errors when the number of customers is increased. Results from this model are compared to the solutions from the 29-aggregate product, 199-customer aggregation model. At full capacity, no real difference is noted as the same six depots remain open and total costs are near equivalent. Results from the 90, 80, 50, and 30 percent depot throughput capacity models for this version differ from those of the 29-aggregate product, 113-customer aggregation version. Additional runs have been required where the solution for 29-aggregate product , 113-customer aggregation model is fixed in these subsequent models. Table 4.12 shows that these additional runs provide equivalent or lower solution gaps. Based on these results, additional customer zones would not result in increased detail or significant differences in total operating costs.

All model versions up to this point have not restricted the maximum distance between depot and customer. As this distance is limited, more depots may be required to satisfy customer demand or the solution may retain high cost and less efficient facilities just to meet this restriction. These additional facilities improve delivery times and customer service yet increase total operating costs. With recent improvements in transportation services, delivery times have been improved significantly. Therefore, the additional cost to retain depots to maintain customer service levels may not be warranted under current conditions. This study ran a model with the depot to customer distance restricted to 1000 miles for the 29-aggregate products, 113-customer aggregation, full capacity model. Table 4.13 compares the results between the restricted and unrestricted versions.

Table 4.12: Solutions for the 29-aggregate products, 199-customer aggregation model demonstrate that different customer aggregations produce essentially the same depot closure decisions.

| Depot Throughput Capacity % | Remarks | Run Times (min) | Total Costs (000) | Soln Gap | Number of Open Depots | Open Depots |
|---|---|---|---|---|---|---|
| Full | | 116 | 823,150 | 10 | 6 | Mech/ Ogden/ Jax Puget/ Hill / Corpus |
| 90 | | 132 | 824,600 | 11 | 6 | Mech/ Ogden/ San Diego Jax/ Hill/ Corpus |
| 90 | Locked open the depot solution from the 29-aggregate products 90 % capacity run | 63 | 824,585 | 11.294 | 5 | Mech/ Ogden/ San Diego Jax/ Hill |
| 80 | | 173 | 833,751 | 10 | 5 | San Joaq / Mech / Ogden Jax / Hill |
| 80 | Locked open the depot solution from the 29-aggregate products 80% capacity run | 141 | 833,821 | 9.77 | 7 | Mech/ Ogden/ San Diego Jax/ Puget/ Hill / Corpus |
| 50 | | 82 | 834,831 | 30 | 12 | San Joaq / Memphis/ Mech Columbus / Ogden / Richmond San Diego / Barstow / Albany Jax / Hill / Cherry Point |
| 50 | Locked open the depot solution from the 29-aggregate products 50% capacity run | 29 | 831,501 | 27.07 | 9 | San Joaq / Memphis/ Mech Columbus / Ogden / San Antonio Richmond / San Diego / Barstow |
| 30 | | 64 | 782,591 | 40 | 20 | all open except Tobyhanna McClellan / Anniston Letterkenny / Red River |
| 30 | Locked open the depot solution from the 29-aggregate products 30% capacity run | 38 | 777,594 | 25 | 16 | all open except Tobyhanna McClellan / Barstow / Norfolk Anniston / Albany / Letterkenny Tinker / Cherry Point |

When this distance is restricted, total operating costs rise: The increase is the result of retaining higher-cost facilities sufficiently close to "reach" customers. Figure 4.4 shows that a small percentage of total demand is satisfied beyond a 1,000 mile range even when there is no range restriction: This implies that there should not be a significant change in outbound costs as range is restricted to 1,000 miles which is the case.

An additional run is made with a 300-mile limitation to determine the effects on total costs and the number of recommended depots remaining open. As expected total costs increase dramatically and the number of open depots increases to 16. In this solution, both capacity violation penalties and lost demand penalties (where it is more economical to not satisfy certain levels of customer demand) are incurred.

Table 4.13: Two models are created where the maximum distance between depot and customer is set at 7500 miles (unrestricted) and 1000 miles (restricted). This table shows that cost for the two models only varies slightly.

| | Fixed Costs | Variable Costs | Replenisment Costs | Outbound Costs | Total Costs | Depots |
|---|---|---|---|---|---|---|
| Restricted 1000 mile limit | 83200 | 105925 | 10659 | 354993 | 554777 | Sharpe / Mech / Ogden Jax / Tinker / Corpus |
| Unrestricted 7500 mile limit | 68700 | 87990 | 12470 | 353999 | 523159 | Mech / Ogden / Jax Puget / Hill / Corpus |

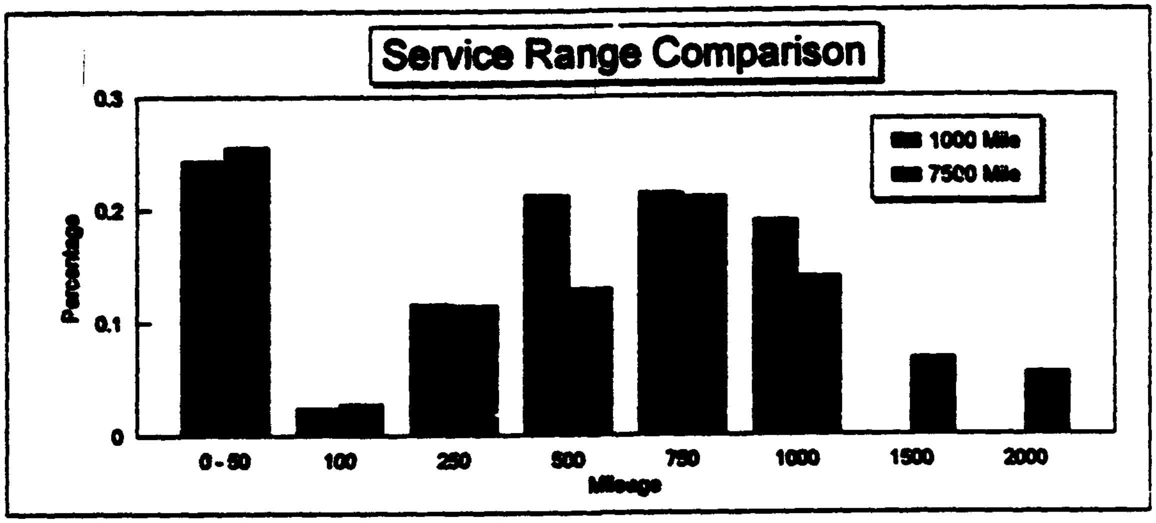


Figure 4.4: Two models are created where the maximum distance between depot and customer is either 7500 miles (unrestricted) and 1,000 miles (restricted). This histogram presents the percentage of customer demand satisfied at the various depot to customer distances. Because most demand is satisfied within the 1,000 mile range even when range is unrestricted, there is not a significant increase in total costs.

# V. CONCLUSIONS AND RECOMMENDATIONS

## A. CONCLUSIONS

This thesis shows how the Defense Logistics Agency (DLA) can save over 300 million dollars annually through depot closure and reorganization. This conclusion comes from extensive analysis of DLA's distribution network using the SAILS model. This thesis derives a 29-product, 113-customer aggregation scheme which renders a SAILS model of DLA that is easy to use and retains essential fidelity. Extensive comparisons between this aggregation scheme and others (44-, 49-, and 67-product; and 199- and 113-customer aggregations) at depot throughput capacities of 100, 90, 80, 50, and 30 percent of remaining capacity show that:

- DLA depots currently have excess throughput capacity available; and
- alternate solutions are possible under the current DLA distribution network.

A discussion of each of these points is presented in the following paragraphs.

DLA depots currently have excess capacity. Even when customer service range is restricted to 1,000 miles from the supplying depot, significant cost reductions in distribution network costs can be achieved without a corresponding decrease in customer service levels.

Results from the different aggregation schemes show that alternate solutions are possible at about the same cost level. As the solution from the recommended model version is fixed in those models which deviate from the 29-product, 113-customer aggregation version equivalent solutions are obtained. For this reason and the fact that the smaller version results in responsive SAILS execution, the 29-product, 113-customer aggregation model is recommended to model the DLA distribution network.

Recall that a customer service restriction where the maximum distance between depot and customer is restricted to 1000 miles led to an increase in total operating costs of over 30 million dollars. As this distance is limited, more depots may be required to satisfy customer demand or the solution may retain high cost and less efficient facilities just to meet this restriction. This study contends that with recent improvements in transportation services and delivery times no significant improvement in customer service is obtainable by ensuring depots are located "close" to or even collocated with all customers.

## B. RECOMMENDATIONS

Though the personal computer version of the SAILS model used in this study accommodates a large transaction file, certain aspects of model setup should still be performed outside SAILS . Because SAILS does not possess all of the rate structures for modes used by DOD, this study recommends that transportation rates for each product aggregation, depot, and customer link be developed outside the model and provided as user-defined values. Because of the limited nature of this study and the lack of readily available data, this approach has not been feasible.

DLA depots currently have excess capacity. Depot closure and reorganization is inevitable under declining Defense budgets. This thesis has demonstrated the flexibility of the SAILS model and its usefulness as a tool to make these closure decisions. Though major concerns exist within DLA about data aggregation, this thesis has shown that data aggregation does not lead to significant modeling discrepancies within SAILS. The 29-aggregate product, 113-customer aggregation model is the means to model DLA's distribution network and SAILS is the tool to make these depot closure decisions.

## APPENDIX A

The following mathematical formulation is the general form of the SAILS model:

**MODEL FORMULATION**

### Indices

| | |
|---|---|
| i | Products (aggregated groups of National Stock Numbers) |
| v | Suppliers (aggregated supplier regions) |
| d | Distribution depots |
| c | Customers (aggregated customer regions) |

### Data

| | |
|---|---|
| $SUP_{i,v}$ | Supplies of each product by supplier |
| $BUY_{i,v}$ | Cost of each product by supplier |
| $INB_{i,v,d}$ | Inbound transportation cost per product unit, by vendor/depot |
| $VCST_{i,d}$ | Variable handling cost by product/depot |
| $FCST_{d}$ | Fixed cost of operating the depot |
| $BRDN_{i,d}$ | Burden rate per product unit by depot |
| $LCAP_{d}$ $UCAP_{d}$ | Lower/Upper capacity of depot (in burden units) |
| $OUTB_{i,d,c}$ | Outbound transportation cost per product unit, by depot/customer |
| $OUTBD_{i,v,c}$ | Outbound transportation cost by product from vendor to customer |
| $DEM_{i,c}$ | Demand by product/customer |

## VARIABLES

| | |
|---|---|
| $X_{i,v,d}$ | Inbound flows by product from supplier to depot |
| $Y_{i,d,c}$ | Outbound flows by product from depot to customer |
| $Z_d$ | Binary variable to open/close depot |
| $Q_{i,d,c}$ | Binary variable for sole sourcing by product/depot to customer |
| $P_{i,v,c}$ | Plant direct shipments by product from supplier to customer |

## FORMULATION

**MIN** $\sum_{ivd}(BUY_{iv} + INB_{ivd} + VCST_{id})X_{ivd} + \sum_{idc}(OUTB_{idc}Y_{idc}) + \sum_d(FCST_dZ_d) + \sum_{ivc}(BUY_{iv} + OUTBD_{ivc})P_{ivc}$

**subj to**

1) $\sum_d X_{ivd} + \sum_c P_{ivc} \leq SUPPLY_{iv} \quad \forall\ i,v$

2) $\sum_d Y_{idc} + \sum_v P_{ivc} \geq DEM_{ic} \quad \forall\ i,c$

3) $\sum_{iv}(BRDN_{id}X_{ivd}) \leq UCAP_dZ_d \quad \forall\ d$
   $\sum_{iv}(BRDN_{id}X_{ivd}) \geq LCAP_dZ_d \quad \forall\ d$

4) $\sum_d(FCST_dZ_d) \leq BUDGET$

5) $Q_{idc} \leq Z_d \quad \forall\ i,d,c$

6) $\sum_v X_{ivd} \geq \sum_c Y_{idc} \quad \forall\ i,d$

7) $Y_{idc} \leq DEM_{i,c}\, Q_{idc} \quad \forall\ i,d,c$
   $\sum_d Q_{idc} = 1 \quad \forall\ i,c$

**CONSTRAINT EXPLANATION**

1) Demand can not exceed supplier's capacity.

2) All customer demand must be met.

3) For each depot, throughput must not exceed depot capacity. Since handling of appregate products is not uniform, a burden rate is determined for each aggregate product.

4) The fixed cost of operating depots must remain within budgetary constraints.

5) This constraint ensures that "sole sourcing" a customer zone assignments can only be made to open depots.

6) This is the flow balance constraint.

7) Customers are sole sourced for each product to a specific depot.

# APPENDIX B

Table B1. Represents the sixty-eight FSC product groupings managed by DLA

| FSC PRODUCT GROUP | DESCRIPTION | FSC PRODUCT GROUP | DESCRIPTION |
|---|---|---|---|
| 10 | Weapons | 53 | Hardware & Abrasive |
| 12 | Fire Control Equip | 54 | Prefabricated Structures & Scaffolding |
| 14 | Guided Missiles Equip | 55 | Lumber, Millwork, Plywood, & Veneer |
| 15 | Acft & Airframe Structural Comps | 56 | Construction & Building Materials |
| 16 | Acft Comps & Accessories | 58 | Communication Equip |
| 17 | Acft Launcing, Ldg,&Gnd Handling | 59 | Electrical & Electronic Equip/Comp |
| 20 | Ship & Marine Equip | 60 | Fiber Optic Matls, Comps, Assys |
| 22 | Railway Equip | 61 | Electric Wire & Power & Dist |
| 24 | Tractors | 62 | Lighting Fixtures & Lamps |
| 25 | Vehicular Equip Components | 63 | Alarm & Signal Systems |
| 26 | Tires | 65 | Medical, Dental, & Veterinary Equip |
| 28 | Engines, Turbines, & Comps | 66 | Instruments & Laboratory Equip |
| 29 | Engine Accessories | 67 | Photographic Equip |
| 30 | Mechanical Power Transmission | 68 | Chemicals & Chemical Products |
| 31 | Bearings | 69 | Training Aids & Devices |
| 32 | Woodworking Machinery & Equip | 70 | General Purpose ADPE, Software |
| 34 | Metalworking Machinery | 71 | Furniture |
| 35 | Service & Trade Equip | 72 | Household & Coml Furnishings |
| 36 | Special Industry Machinery | 73 | Food Preparation & Serving Equip |
| 37 | Agricultural Machinery & Equip | 74 | Office Machines, Visible Record Equip |
| 38 | Construction, Mining, Excavating | 75 | Office Supplies & Devices |
| 39 | Materials Handling Equip | 76 | Books, Maps, & Other Publications |
| 40 | Rope, Cable, Chain, & Fittings | 79 | Cleaning Equip & Supplies |
| 41 | Refrigeration & Air Cond Equip | 80 | Brushes, Paints, Sealers, & Adhesives |
| 42 | Fire Fighting, Rescue & Safety Equip | 81 | Containers, Packaging, & Packing Supplies |
| 43 | Pumps & Compressors | 83 | Textiles,Leather,Furs, Notions, Yarn, Tents |
| 44 | Furnace, Steam, Plant, Drying Equip | 84 | Clothing & Individual Equip |
| 45 | Plumbing, Heating, & Sanitation Equip | 85 | Toiletries |
| 46 | Water Purification & Sewage Treat | 89 | Subsistence |
| 47 | Pipe, Tube, & Hose | 91 | Fuels, Lubricants, Oils, & Waxes |
| 48 | Valves | 93 | Nonmetallic Fabricated Materials |
| 49 | Maintenance & Repair Shop Equip | 95 | Metal Bars, Sheets & Shapes |
| 51 | Hand Tools | 96 | Ores, Minerals, & their Primary Products |
| 52 | Measuring Tools | 99 | Miscellaneous |

Table B2. Represents a detailed breakdown of the product classes available in FSC product group 53.

| FSC | Description |
|---|---|
| 5305 | Screws |
| 5306 | Bolts |
| 5307 | Studs |
| 5310 | Nuts & Washers |
| 5315 | Nails, Keys & Pins |
| 5320 | Rivets |
| 5325 | Fastening Devices |
| 5330 | Packing & Gasket Materials |
| 5335 | Metal Screening |
| 5340 | Miscellaneous Hardware |
| 5345 | Disks & Stones Abrasive |
| 5350 | Abrasive Materials |
| 5355 | Knobs & Pointers |
| 5360 | Coil, Flat, & Wire Springs |
| 5365 | Rings, Shims & Spacers |

# APPENDIX C

Table C1 Listing of FSC's represented in the material release order files for FY 92. Additionally, this table provides the mean unit wt standard deviation, mean extended weight (requisition quantity multiplied by unit weight), and standard deviation extended weight.

| FSC | Description | Freq | Mean Weight | Std Dev Weight | Mean Ext Weight | Std Dev Ext Weight |
|---|---|---|---|---|---|---|
| 1005 | Guns thru 30 MM | 52976 | 1.09 | 3.53 | 41.01 | 508.66 |
| 1010 | Guns Over 30 MM Up To 75 MM | 4009 | 1.44 | 1.48 | 20.38 | 159.9 |
| 1015 | Guns 75 MM Thru 125 MM | 6656 | 4.09 | 7.47 | 25.43 | 295.3 |
| 1020 | Guns Over 125 MM Thru 150 MM | 2505 | 2.47 | 7.14 | 8.47 | 53.13 |
| 1025 | Guns Over 150 MM Thru 200 MM | 3987 | 4.62 | 8.68 | 29.93 | 151.68 |
| 1030 | Guns Over 200 MM Thru 300 MM | 27 | 1.02 | 1.44 | 3.25 | 6.35 |
| 1035 | Guns Over 300 MM | 58 | 2.95 | 0.48 | 12.55 | 13.71 |
| 1040 | Chemical Weapons and Equip | 489 | 1.39 | 0.83 | 4.99 | 17.75 |
| 1045 | Launchers Torpedo & Depth Charge | 442 | 1.89 | 0.19 | 9.31 | 24.87 |
| 1055 | Launchers Torpedo & Pyrotechnic | 1548 | 1.88 | 1.79 | 15.43 | 98.7 |
| 1075 | Degaussing & Mine Sweeping Equip | 163 | 1.93 | 0.45 | 51.06 | 312.32 |
| 1080 | Camouflage & Deception Equip | 223 | 1.88 | 0 | 108.87 | 248.39 |
| 1090 | WPNS Assy Interchange | 368 | 6.19 | 8.39 | 27.45 | 80.62 |
| 1095 | Miscellaneous Weapons | 3545 | 1.3 | 2.03 | 34.72 | 288.41 |
| 1210 | Fire Control Directors | 23 | 2.19 | 1.74 | 3.28 | 3.06 |
| 1220 | Fire Control Computing Sights & Devices | 387 | 0.9 | 0.69 | 5.28 | 12.85 |
| 1240 | Optical Sighting & Ranging Equip | 3587 | 1.35 | 5.91 | 9.21 | 48.99 |
| 1250 | Fire Control Stabilizing Mechanisms | 1 | 1.64 | | 9.84 | |
| 1260 | Fire Cntl Designating-Indicating Equip | 287 | 0.14 | 0.11 | 0.9 | 1.89 |
| 1265 | Fire Control Equip Except Airborne | 83 | 1.31 | 0.51 | 2.58 | 3.51 |
| 1270 | Aircraft Gunnery Fire Control Comps | 978 | 0.53 | 0.3 | 2.98 | 8.99 |
| 1280 | Aircraft Bombing Fire Control Comps | 447 | 0.24 | 0.15 | 0.97 | 2.95 |
| 1285 | Fire Control Radar Equip Except Air | 1038 | 3.01 | 7.07 | 8.73 | 28.3 |
| 1287 | Fire Control Sonar Equip | 7 | 1.48 | 0 | 1.48 | 0 |
| 1290 | Miscellaneous Fire Control Equip | 2011 | 0.81 | 1.23 | 4.24 | 12.13 |
| 1420 | Guided Missile Components | 643 | 1.8 | 4.29 | 17.86 | 71.54 |
| 1430 | Guided Missile Remote Control Systems | 3089 | 1.65 | 3.31 | 11.32 | 42.38 |
| 1440 | Launchers Guided Missile | 9930 | 1.85 | 2.77 | 13.27 | 55.92 |
| 1450 | Guided Missile Handling Servicing Equip | 1336 | 6.05 | 8.52 | 31.1 | 107.41 |
| 1560 | Airframe Structural Comps | 125447 | 3.48 | 8.47 | 13.98 | 77.31 |
| 1610 | Aircraft Propellers | 2982 | 2.11 | 4.12 | 12.03 | 88.06 |
| 1615 | Helicopter Rotor Blades-Drive Mech | 13984 | 1.19 | 3.33 | 7.09 | 35.93 |
| 1620 | Aircraft Landing Gear Comps | 8325 | 2.18 | 6.83 | 16.8 | 178.48 |
| 1630 | Aircraft Wheel & Brake Systems | 7470 | 2.15 | 4.08 | 22.02 | 113.48 |
| 1650 | Aircraft Hydraulic Vacuum De-icing Comps | 29875 | 1.39 | 14.51 | 8.99 | 83.87 |
| 1660 | Aircraft Air Conditioning Heating Equip | 10744 | 0.63 | 6.67 | 3.61 | 13.86 |
| 1670 | Parachutes Recovery Sys & Tie Down Equip | 6610 | 4.12 | 8.9 | 144.38 | 881.82 |
| 1680 | Misc Aircraft Accessories Comps | 81288 | 1.33 | 6.28 | 7.62 | 63.3 |
| 1710 | Aircraft Arresting Barrier & Equip | 617 | 12.17 | 6.48 | 59.28 | 144.64 |
| 1720 | Aircraft Launching Equip | 112 | 12.21 | 6.06 | 230.79 | 635.48 |
| 1730 | Aircraft Ground Servicing Equip | 22445 | 12.38 | 35.4 | 62.1 | 307.12 |
| 1740 | Airfield Specialized Trucks & Trailers | 1680 | 18.64 | 44.41 | 123.38 | 720.22 |
| 2010 | Ship & Boat Propulsion Comps | 3020 | 28.57 | 80.96 | 163.56 | 1412.77 |
| 2020 | Rigging & Rigging Gear | 48 | 18.35 | 8.31 | 97.88 | 167.74 |
| 2030 | Deck Machinery | 1283 | 6.48 | 12.29 | 18.13 | 58.17 |
| 2040 | Marine Hardware & Hull Items | 8197 | 21 | 89.48 | 489.33 | 16380.63 |
| 2050 | Buoys | 33 | 8.75 | 2.78 | 388.88 | 1185.61 |
| 2090 | Miscellaneous Ship & Marine Equip | 3808 | 32.33 | 51.79 | 1343.89 | 85179.97 |
| 2240 | Locomotive & Rail Car Accessories | 127 | 21.82 | 18.39 | 385.76 | 727.82 |
| 2250 | Track Materials Railroad | 37 | 8.19 | 15.88 | 1308.88 | 1828.87 |
| 2410 | Tractors Full Track Low Speed | 19 | 85.49 | 167.23 | 185.19 | 278.2 |
| 2420 | Tractors Wheeled | 15 | 11.5 | 15.61 | 11.58 | 15.58 |
| 2510 | Vehicular Cab Body Frame Structural Comp | 147888 | 22.08 | 38.63 | 58.21 | 432.38 |
| 2520 | Vehicular Power Transmission Comps | 80748 | 11.53 | 38.06 | 58.02 | 882.87 |
| 2530 | Vehicular Brake Steering Axle Wheel Comp | 204882 | 11.82 | 47.08 | 52.42 | 3277.37 |
| 2540 | Vehicular Furniture & Accessories | 311448 | 8.88 | 21.89 | 28.09 | 380.68 |
| 2590 | Miscellaneous Vehicular Comps | 87477 | 8.38 | 27.43 | 28.83 | 338.48 |
| 2620 | Tires & Tubes Pneumatic Aircraft | 1891 | 14.85 | 11.51 | 50.37 | 117.03 |
| 2805 | Gas Reciprocating Engine-Except Aircraft | 18810 | 14.35 | 41.9 | [illegible] | 762.08 |
| 2810 | Gas Reciprocating Eng-Aircraft &Comps | 402 | 1.43 | 3.19 | [illegible] | 7754.09 |
| 2815 | Diesel Engines & Comps | 44384 | 18.21 | 53.1 | [illegible] | 888.85 |
| 2820 | Steam Engines Reciprocating & Comps | 8 | 5.28 | 4.75 | 8.37 | 6.74 |
| 2825 | Steam Turbines & Comps | 5320 | 7.44 | 44.82 | 16.4 | 105.06 |
| 2830 | Water Turbines-Water Wheels & Comps | 1 | 27 | | 108 | |
| 2835 | Gas Turbines & Jet Eng Except Aircraft | 6783 | 3.19 | 9.63 | 32.67 | 349.44 |
| 2840 | Gas Turbines & Jet Engines Aircraft | 17719 | 0.68 | 1.98 | 37.84 | 773.91 |
| 2850 | Gasoline Rotary Engines & Comps | 1 | 20.85 | | 1042.7 | |
| 2895 | Miscellaneous Engines & Comps | 174 | 3.4 | 11.03 | 4.63 | 11.78 |
| 2910 | Engine Fuel Sys Components Nonaircraft | 128847 | 3.11 | 13.33 | 12.5 | 115.97 |
| 2915 | Engine Fuel Systems Components Aircraft | 6624 | 1.27 | 6.85 | 12.47 | 143.96 |

Table C1. Continued

| PSC | Description | Freq | Mean Weight | Std Dev Weight | Mean Ext Weight | Std Dev Ext Weight |
|---|---|---|---|---|---|---|
| 2920 | Engine Electrical Sys Compo Nonaircraft | 111821 | 4.29 | 10.48 | 13.78 | 88.61 |
| 2925 | Engine Electrical Sys Compo Aircraft | 4673 | 0.62 | 0.98 | 15.05 | 385.58 |
| 2930 | Engine Cooling Sys Compo-Nonaircraft | 38072 | 14.6 | 38.68 | 61.03 | 882.81 |
| 2935 | Engine Cooling Sys Compo-Aircraft | 891 | 18.9 | 47.82 | 1951.33 | 43046.9 |
| 2940 | Engine Air & Oil Filters - Nonaircraft | 119112 | 3.7 | 7.3 | 23.5 | 308.24 |
| 2945 | Engine Air & Oil Filters - Aircraft | 2604 | 0.37 | 0.99 | 4.96 | 42.1 |
| 2950 | Turbosuperchargers | 531 | 16.86 | 15.43 | 48.22 | 144.49 |
| 2990 | Misc Engine Accessories-Nonaircraft | 43069 | 0.83 | 14.48 | 30.33 | 1113.35 |
| 2995 | Misc Engine Accessories-Aircraft | 6166 | 0.77 | 2.03 | 3.57 | 15.68 |
| 3010 | Torque Converters & Speed Changers | 17067 | 18.67 | 44.65 | 47.29 | 236.43 |
| 3020 | Gears Pulleys Sprockets & Trans Chain | 40482 | 4.76 | 19.13 | 27.6 | 703.16 |
| 3030 | Belting Drive Belts Fan Belts & Access | 77856 | 3.13 | 14.7 | 24.69 | 263.99 |
| 3040 | Miscellaneous Power Transmission Equip | 50863 | 7.31 | 29.18 | 27.58 | 611.03 |
| 3110 | Bearings Antifriction Unmounted | 175990 | 1.57 | 7.91 | 16.1 | 297.41 |
| 3120 | Bearings Plain Unmounted | 151636 | 3.99 | 33.96 | 12.12 | 697.82 |
| 3130 | Bearings Mounted | 5832 | 4.17 | 8.04 | 27.07 | 298.11 |
| 3210 | Sawmill & Planing Mill Machinery | 8 | 1.28 | 2.36 | 4.27 | 9.81 |
| 3220 | Woodworking Machines | 343 | 183.5 | 382.27 | 179.6 | 389.88 |
| 3230 | Tools - Attachments For Woodworking Mach | 2303 | 0.98 | 1.57 | 19.16 | 43.3 |
| 3405 | Saws & Filing Machines | 128 | 72.01 | 287.21 | 87.79 | 298.68 |
| 3413 | Drilling & Tapping Machines | 237 | 268.92 | [illegible] | 329.60 | 289 |
| 3415 | Grinding Machines | 880 | 57.8 | 70.77 | 80.21 | 121.04 |
| 3416 | Lathes | 28 | 48.99 | 117.47 | 286.76 | 819.23 |
| 3417 | Milling Machines | 230 | 20.26 | 66.5 | 37.16 | 103.43 |
| 3419 | Miscellaneous Machine Tools | 172 | 78.1 | 177.14 | 282.08 | 1416.74 |
| 3424 | Metal Heat Treating Equip | 11 | 437.3 | 389.84 | 629.36 | 682.82 |
| 3426 | Metal Finishing Equip | 328 | 8.85 | 40.54 | 38.21 | 140.27 |
| 3431 | Electric Arc Welding Equip | 4614 | 17.01 | 66.6 | 46.08 | 387.38 |
| 3432 | Electric Resistance Welding Equip | 70 | 39.14 | 78.94 | 47.7 | 79.82 |
| 3433 | Gas Welding Heat Cutting-Metalizing Equip | 5470 | 4.79 | 13.69 | 14.39 | 116.2 |
| 3436 | Welding Positioners & Manipulators | 33 | 112.28 | 91.6 | 142.93 | 194.99 |
| 3438 | Miscellaneous Welding Equip | 183 | 32.5 | 19.83 | 69.16 | 78.39 |
| 3439 | Misc Welding soldering & Brazing Supply | 68864 | 2.85 | 7.27 | 69.92 | 916.5 |
| 3441 | Bending & Forming Machines | 302 | 176.68 | 482.33 | 277.87 | 1121.94 |
| 3442 | Hydraulic & Pneumatic Presses Power Dr | 14 | 136.61 | 283.69 | 136.89 | 283.46 |
| 3443 | Mechanical Presses Power Driven | 12 | 3.16 | 6.63 | 6.65 | 7.04 |
| 3444 | Manual Presses | 287 | 476.18 | 616.23 | 882.48 | 689.92 |
| 3445 | Punching & Shearing Machines | 220 | 46.23 | 82.76 | 113.42 | 387.4 |
| 3446 | Forging Machinery & Hammers | 21 | 65.97 | 138.73 | 66.85 | 135.48 |
| 3448 | Riveting Machines | 12 | 3.33 | 10.29 | 3.85 | 10.23 |
| 3449 | Misc Secondary Metal Forming-Cutting Mach | 170 | 88.69 | 34.18 | 621.1 | 1875.51 |
| 3450 | Machine Tools portable | 87 | 60 | 32.32 | 76.39 | 46.39 |
| 3455 | Cutting Tools For Machine Tools | 23613 | 0.83 | 2.83 | 14.7 | 448.39 |
| 3456 | Cutting Tools For Secondary Metal Mach | 434 | 1.42 | 6.66 | 6 | 28.47 |
| 3460 | Machine Tool Accessories | 10234 | 3.18 | 12.24 | 28.88 | 218.81 |
| 3465 | Production Jigs Fixtures & Templates | 718 | 0.19 | 0.4 | 2.06 | 6.66 |
| 3510 | Laundry & Dry Cleaning Equip | 1937 | 11.68 | 68.98 | 68.98 | 271.72 |
| 3520 | Shoe Repairing Equip | 11 | 182.16 | 337.81 | 183.16 | 337.1 |
| 3530 | Industrial Sewing Machines & Mobile Textile | 1610 | 60.68 | 148.34 | 78.88 | 220.07 |
| 3540 | Wrapping & Packaging Machinery | 83 | 19.11 | 8.57 | 88.12 | 83.09 |
| 3590 | Miscellaneous Service & Trade Equip | 30 | 0.68 | 0 | 1.16 | 1.63 |
| 3610 | Printing Duplicating & Bookbinding Equip | 2082 | 31.55 | 68.5 | 104.5 | 1867.48 |
| 3611 | Industrial Marking Machines | 274 | 4.83 | 17.2 | 7.82 | 24.11 |
| 3615 | Pulp & Paper Industries Machinery | 78 | 42.08 | 80.27 | 328.86 | 1420.95 |
| 3620 | Textile Industries Machinery | 1 | 330 | . | 300 | . |
| 3630 | Clay-Concrete Products Industries Mach | 1 | 29.44 | . | 412.2 | . |
| 3635 | Crystal & Glass Industries Machinery | 13 | 473 | 0 | 473 | 0 |
| 3650 | Chemical & Pharmaceutical Machinery | 7 | 16.79 | 43.31 | 16.86 | 43.29 |
| 3655 | Gas Generating & Dispensing System | 1989 | 6.98 | 22.86 | 15.69 | 62.06 |
| 3660 | Industrial Size Reduction Machinery | 4 | 1.3 | 0 | 4.85 | 5.87 |
| 3670 | Printed Circuit Board MFG Mach | 1 | 386.01 | . | 1156.03 | . |
| 3680 | Foundry Machinery - Related Equip & Sup | 80 | 29.89 | 39.48 | 817.18 | 3038.27 |
| 3685 | Specialized Metal Container Mfg Mach | 2 | 43 | 0 | 180.5 | 182.03 |
| 3693 | Industrial Assembly Machines | 6 | 1.5 | 0.55 | 1.83 | 0.41 |
| 3694 | Clean Work Stations Environment Equip | 233 | 31.61 | 130.83 | 102.4 | 203.77 |
| 3695 | Miscellaneous Special Industry Machinery | 986 | 14.4 | 20.29 | 28.99 | 61.04 |
| 3710 | Soil Preparation Equip | 24 | 86.67 | 148.05 | [illegible] | 214.94 |
| 3740 | Pest Disease & Frost Control Equip | 1561 | 38.43 | 149.91 | [illegible] | 410.32 |
| 3770 | Saddlery Harness Whips & Furnishings | 604 | 0.84 | 0.86 | [illegible] | 14.74 |
| 3805 | Earth Moving & Excavating Equip | 2087 | 73.88 | 178.21 | 366.79 | 1480.02 |

Table C1. Continued

| FSC | Description | Freq | Mean Weight | Std Dev Weight | Mean Ext Weight | Std Dev Ext Weight |
|---|---|---|---|---|---|---|
| 3810 | Cranes & Crane-Shovels | 763 | 18.24 | 37.48 | 38.23 | 170.36 |
| 3815 | Crane & Crane-Shovel Attachments | 491 | 129.69 | 341.2 | 267.56 | 658.51 |
| 3820 | Mining Rock Drilling Earth Boring Equip | 1288 | 28.64 | 60.66 | 62.21 | 137.25 |
| 3825 | Road Clearing & Cleaning Equip | 1727 | 83.47 | 149.38 | 658.24 | 8588.76 |
| 3830 | Truck & Tractor Attachments | 3785 | 78.28 | 201.67 | 283.53 | 1304.19 |
| 3835 | Petroleum Production-Distribution Equip | 69 | 14.28 | 69.24 | 867.56 | 4869.62 |
| 3895 | Misc Construction Equip | 3911 | 31.13 | 168.62 | 72.86 | 274.89 |
| 3910 | Conveyors | 611 | 51.86 | 76.48 | 617.02 | 3127.8 |
| 3920 | Matl Handling Equip - Nonself Prop | 2516 | 129.17 | 178.44 | 468.61 | 2837.66 |
| 3930 | Warehouse Trucks & Tractors Self-Prop | 4242 | 29.24 | 85.13 | 46.8 | 147.8 |
| 3940 | Blocks Tackle Rigging & Slings | 3732 | 67.88 | 132.69 | 269.05 | 836.21 |
| 3950 | Winches Hoists Cranes & Derricks | 4383 | 83.62 | 167.3 | 167.7 | 833.83 |
| 3960 | Elevators & Escalators | 164 | 28.63 | 18.47 | 286.47 | 571.24 |
| 3990 | Misc Materials Handling Equip | 3391 | 68.21 | 188.64 | 6076.84 | 86642.83 |
| 4010 | Chain & Wire Rope | 46461 | 88.86 | 169.86 | 617.43 | 85277.86 |
| 4020 | Fiber Rope Cordage & Twine | 27177 | 64.62 | 138.43 | 326.41 | 4861.8 |
| 4030 | Fittings For Rope Cable & Chain | 47676 | 4.86 | 16.29 | 42.8 | 387.84 |
| 4110 | Refrigeration Equip | 3374 | 316.71 | 348.51 | 612.86 | 7336.48 |
| 4120 | Air Conditioning Equip | 1666 | 184.2 | 131.86 | 912.24 | 2376.8 |
| 4130 | Refrigeration & Air Conditioning Comp | 27763 | 16.25 | 65.44 | 134.2 | 6846.76 |
| 4140 | Fans Air Circulators & Blower Equip | 26830 | 11.86 | 64.66 | 44.86 | 1808.66 |
| 4210 | Fire Fighting Equip | 30067 | 20.42 | 47.9 | 331.34 | 3682.22 |
| 4220 | Marine Lifesaving & Diving Equip | 12476 | 6.46 | 60.53 | 77.23 | 703.87 |
| 4230 | Decontaminating & Impregnating Equip | 1687 | 8.31 | 12.28 | 43.34 | 825.86 |
| 4240 | Safety & Rescue Equip | 45834 | 2.83 | 12.86 | 82.51 | 808.9 |
| 4310 | Compressors & Vacuum Pumps | 21610 | 16.76 | 72.33 | 40.43 | 417.46 |
| 4320 | Power & Hand Pumps | 61630 | 12.04 | 53.51 | 48.3 | 3848.7 |
| 4330 | Centrifugals, Separators, & Filters | 74429 | 3 | 9.41 | 28.51 | 288.33 |
| 4410 | Industrial Boilers | 1640 | 82.46 | 167.17 | 383.28 | 3088.19 |
| 4420 | Heat Exchangers & Steam Condensers | 1134 | 87.73 | 138.66 | 138.82 | 368.94 |
| 4430 | Industrial Furnaces Kilns Lehrs & Ovens | 65 | 108 | 287.17 | 140.73 | 227.76 |
| 4440 | Driers Dehydrators & Anhydrators | 7068 | 11.21 | 37.84 | 68.39 | 2443.83 |
| 4460 | Air Purification Equip | 1379 | 10.89 | 80.56 | 218.71 | 1498.5 |
| 4510 | Plumbing Fixtures & Accessories | 26562 | 8.66 | 28.18 | 112.28 | 726.87 |
| 4520 | Space Heating Equip & Water Heaters | 13694 | 26.18 | 121.89 | 119.18 | 486.6 |
| 4530 | Fuel Burning Equip Units | 4131 | 4.46 | 14.41 | 24.67 | 86.11 |
| 4540 | Misc Plumbing Heating & Sanitation Equip | [illegible] | 11.82 | 39.5 | 64.11 | 376.86 |
| 4610 | Water Purification Equip | [illegible] | 21.7 | 61.84 | 213.86 | 1888.89 |
| 4620 | Water Distillation Equip Marine & Industrial | [illegible] | 9.43 | 20.53 | 28.2 | 67.34 |
| 4630 | Sewage Treatment Equip | [illegible] | 7.79 | 10.66 | 11.72 | 16.76 |
| 4710 | Pipe & Tube | [illegible] | 4.41 | 30.38 | 283.51 | 6660.38 |
| 4720 | Hose & Tubing Flexible | [illegible] | 3.93 | 22.86 | 77.72 | 13671.49 |
| 4730 | Fittings Hose Pipe & Tube | [illegible] | 0.7 | 5.82 | 6.73 | 182.28 |
| 4810 | Valves Powered | 22183 | 6.4 | 40.57 | 14.81 | 84.34 |
| 4820 | Valves Non-Powered | 102687 | 5.28 | 27.31 | 24.86 | 661.28 |
| 4910 | Motor Vehicle Maintenance Equip | 24236 | 17.22 | 80.36 | 74.83 | 1027.86 |
| 4920 | Aircraft Maint & Repair Shop Equip | 6966 | 7.71 | 13.37 | 44.37 | 287.37 |
| 4921 | Torpedo Maint Repair & Checkout Equip | 73 | 6.37 | 0 | 66.52 | 161.49 |
| 4925 | Ammunition Maintenance Checkout Equip | 28 | 2.34 | 1.03 | 10.62 | 18.46 |
| 4930 | Lubrication & Fuel Dispensing Equip | 30650 | 6.49 | 22.16 | 33.1 | 603.36 |
| 4931 | Fire Control Maintenance Equip | 919 | 1.06 | 1.89 | 4.89 | 19.22 |
| 4933 | Weapons Maintenance Equip | 1914 | 2.19 | 4.51 | 22.51 | 836.86 |
| 4935 | Guided Missile Maintenance Equip | 1666 | 0.86 | 0.66 | 6.5 | 29.62 |
| 4940 | Misc Maintenance Equip | 16864 | 17.37 | 42.61 | 111.12 | 612.32 |
| 5110 | Hand Tools Edged Nonpowered | 176 | 0.94 | 1.84 | 5.44 | 17.14 |
| 5120 | Hand Tools Nonedged Nonpowered | 1483 | 0.67 | 0.63 | 2.8 | 5.66 |
| 5130 | Hand Tools Power Driven | 11 | 7.47 | 3.6 | 20.72 | 35.86 |
| 5133 | Drill Bits Counterbores & Countersinks | 1 | 1.29 | . | 1.29 | . |
| 5140 | Tool & Hardware Boxes | 103 | 1.29 | 0 | 4.17 | 6.94 |
| 5180 | Sets Kits & Outfits of Hand Tools | 18 | 1.29 | 0 | 2.15 | 1.36 |
| 5210 | Measuring Tools Craftsmens | 21 | 1.58 | 1.23 | 2.94 | 3.83 |
| 5220 | Inspection Gauges & Precision Layout | 1582 | 2.34 | 5.17 | 8.61 | 53.66 |
| 5280 | Sets Kits & Outfits of Measuring Tools | 2 | 2.31 | 0 | 3.46 | 1.63 |
| 5305 | Screws | 887630 | 0.5 | 1.68 | 10.87 | 431.5 |
| 5306 | Bolts | 385154 | 0.49 | 2.86 | 8.2 | 107.06 |
| 5307 | Studs | 31304 | 0.36 | 1.63 | 14.02 | 169.24 |
| 5310 | Nuts & Washers | 682369 | 0.38 | 9.3 | 8.16 | 373.71 |
| 5315 | Nails Keys & Pins | 243666 | 0.66 | 7.61 | 10.77 | 487.86 |
| 5320 | Rivets | 203482 | 0.28 | 2.49 | 10.23 | 878.33 |
| 5325 | Fastening Devices | 102863 | 0.14 | 0.48 | 2.99 | 51.86 |

Table C1. Continued

| FSC | Description | Freq | Mean Weight | Std Dev Weight | Mean Ext Weight | Std Dev Ext Weight |
|---|---|---|---|---|---|---|
| 5330 | Packing & Gasket Materials | 1082186 | 0.72 | 12.53 | 4.38 | 128.01 |
| 5335 | Metal Screening | 1411 | 34.34 | 86.84 | 288.54 | 1268.24 |
| 5340 | Misc Hardware | 663263 | 1.18 | 5.41 | 13.3 | 308.71 |
| 5345 | Disks & Stones Abrasive | 27 | 1.21 | 0.24 | 6.96 | 5.87 |
| 5350 | Abrasive Matls | 38 | 32.87 | 21.15 | 43.14 | 34.83 |
| 5355 | Knobs & Pointers | 69862 | 0.09 | 0.41 | 0.46 | 2.90 |
| 5360 | Coil, Flat, & Wire Springs | 124530 | 0.38 | 3.51 | 3.19 | 51.75 |
| 5365 | Rings, Shims, & Spacers | 232751 | 0.23 | 4.68 | 2.62 | 86.76 |
| 5410 | Prefabricated & Portable Building | 840 | 28.88 | 48.48 | 148.28 | 733.83 |
| 5411 | Rigid Wall Shelters | 194 | 0.41 | 1.13 | 1.89 | 1.82 |
| 5420 | Bridges Fixed & Floating | 891 | 23.77 | 28.93 | 604.98 | 6188.03 |
| 5430 | Storage Tanks | 1011 | 14.08 | 60.90 | 49.86 | 275.87 |
| 5440 | Scaffolding Equip & Concrete Forms | 1864 | 48.27 | 41.34 | 127.88 | 280.6 |
| 5445 | Prefabricated Tower Structures | 28 | 38.7 | 17.58 | 94.52 | 84.91 |
| 5450 | Misc Prefabricated Structures | 1137 | 87.87 | 444.71 | 1898.37 | 7787.31 |
| 5510 | Lumber & Related Basic Wood Matls | 4224 | 6.38 | 18.62 | 12088.08 | 68848.73 |
| 5520 | Millwork | 2 | 68.49 | 0 | 1388.7 | 484.28 |
| 5530 | Plywood & Veneer | 203 | 44.54 | 18.48 | 4679.08 | 24881.28 |
| 5660 | Fencing Fences & Gates | 1916 | 82.23 | 72.38 | 4236.82 | 28488.31 |
| 5680 | Misc Construction Matl | 3 | 1688.79 | 1372.71 | 188206.82 | 284278.9 |
| 5805 | Telephone & Telegraph Equip | 13001 | 3.22 | 7.46 | 89.12 | 332.22 |
| 5810 | Communications Security Equip | 210 | 2.65 | 6.02 | 11.27 | 18.16 |
| 5811 | Other Cryptologic Equip & Comps | 55 | 2.05 | 0.04 | 6.2 | 6.25 |
| 5815 | Teletype & Facsimile Equip | 5730 | 0.43 | 1.78 | 2.87 | 18.5 |
| 5820 | Radio TV Equip Except Airborne | 4277 | 5.48 | 11.12 | 38.98 | 218.09 |
| 5821 | Radio TV Equip Airborne | 1027 | 0.54 | 1.83 | 6.29 | 57.08 |
| 5825 | Radio Navigation Equip- Non Airborne | 183 | 7.28 | 14.2 | 18.81 | 28.31 |
| 5826 | Radio Navigation Equip- Airborne | 1233 | 0.38 | 0.5 | 1.81 | 6.83 |
| 5830 | Intercom Public Address Sys-Non | 615 | 8.88 | 8.32 | 18.5 | 28.83 |
| 5831 | Intercom Public Address Sys-Air | 285 | 0.79 | 1.38 | 2.83 | 8.08 |
| 5835 | Sound Recording & Reproducing Equip | 2787 | 1.81 | 3.88 | 107.38 | 1012.33 |
| 5836 | Video Recording & Reproducing Equip | 2784 | 1.08 | 1.23 | 88.23 | 183.88 |
| 5840 | Radar Equip Except Airborne | 1882 | 2.87 | 3.17 | 63.11 | 1328.32 |
| 5841 | Radar Equip Airborne | 2174 | 0.55 | 0.6 | 3.54 | 28.2 |
| 5845 | Underwater Sound Equip | 1188 | 0.98 | 6.68 | 28.88 | 477.88 |
| 5850 | Visible/Invisible Light Com Equip | 344 | 3.19 | 4.85 | 12.72 | 28.01 |
| 5855 | Night Vision Equip | 8841 | 0.6 | 1.38 | 6.81 | 28.88 |
| 5860 | Stimulated Coherent Radiation Devices | 113 | 1.48 | 1.81 | 3.87 | 6.99 |
| 5865 | Elect Countermeasures & Quick React | 1380 | 0.67 | 0.88 | 6.88 | 18.90 |
| 5895 | Misc Communication Equip | 14881 | 1.37 | 8.80 | 14.84 | 116.16 |
| 5905 | Resistors | 234183 | 0.16 | 2.06 | 1.39 | 42.1 |
| 5910 | Capacitors | 117821 | 0.17 | 1.87 | 1.37 | 16.46 |
| 5915 | Filters & Networks | 28988 | 1.12 | 4.78 | 4.94 | 127.31 |
| 5920 | Fuses & Lightning Arrestors | 149148 | 0.2 | 1.98 | 3.08 | 28.27 |
| 5925 | Circuit Breakers | 64617 | 1.34 | 6.7 | 6.6 | 217.43 |
| 5930 | Switches | 274876 | 0.98 | 3.12 | 2.42 | 111.38 |
| 5935 | Connectors Electrical | 488888 | 0.23 | 7.18 | 3.83 | 220.86 |
| 5940 | Lugs Terminals & Terminal Strips | 138432 | 0.87 | 2.82 | 12.07 | 1080.14 |
| 5945 | Relays & Solenoids | 116379 | 0.74 | 1.87 | 2.79 | 38.39 |
| 5950 | Coils & Transformers | 60676 | 3.73 | 21.19 | 10.84 | 123.08 |
| 5955 | Piezoelectric Crystals | 11381 | 0.2 | 2.57 | 0.73 | 3.92 |
| 5960 | Electron Tubes & Assoc Hardware | 38949 | 2.22 | 7.82 | 14.92 | 1081.51 |
| 5961 | Semiconductor Devices & Assoc Hardware | 188721 | 0.08 | 0.28 | 1.46 | 47.28 |
| 5962 | Microcircuits - Electronics | 168826 | 0.11 | 14.61 | 0.78 | 48.34 |
| 5963 | Electronic Modules | 3881 | 0.31 | 2.84 | 1.92 | 98.90 |
| 5965 | Headsets Handsets Microphones & Speakers | 42840 | 2.38 | 7.61 | 18.08 | 131.80 |
| 5970 | Elec Insulators & Insulating Matl | 63128 | 1.38 | 8.54 | 28.38 | 880.52 |
| 5975 | Electrical Hardware & Supplies | 128887 | 2.36 | 10.96 | 54.33 | 384.77 |
| 5977 | Electrical Contact Brushes & Electrodes | 18838 | 0.41 | 4.87 | 8.15 | 282.88 |
| 5980 | Optoelectronic Devices & Assoc Hardware | 12440 | 0.07 | 0.92 | 0.88 | 7.91 |
| 5985 | Antennas Waveguides & Related Equip | 88834 | 2.33 | 8.43 | 9.28 | 63.95 |
| 5990 | Synchros & Resolvers | 7868 | 1.07 | 2.04 | 8.62 | 489.91 |
| 5995 | Cable Cord wire Assemblies- Comm Equip | 90804 | 1.98 | 3.98 | 8.41 | 60.6 |
| 5998 | Misc Electrical Equip | 30632 | 0.69 | 1.2 | 2.48 | 19.81 |
| 5999 | Misc Electronic Components | 104884 | 0.25 | 1.16 | 8.7 | 187.88 |
| 6015 | Fiber Optic Cables | 8 | 0.01 | 0 | 5.56 | 8.18 |
| 6020 | Fiber Optic Cable Assy & Harness | 167 | 0.06 | 0.05 | 0.34 | 0.78 |
| 6025 | Fiber Optic | 6 | 0.53 | 0 | 15.34 | 11.34 |
| 6026 | Fiber Optic | 14 | 0.53 | 0 | 4.04 | 2.98 |
| 6030 | Fiber Optic Devices | 16 | 0.90 | 1.78 | 1.86 | 3.21 |

Table C1. Continued

| FSC | Description | Freq | Mean Weight | Std Dev Weight | Mean Ext Weight | Std Dev Ext Weight |
|---|---|---|---|---|---|---|
| [illegible] | Fiber Optic Cables | 4 | 0.53 | 0 | 2.35 | 0.32 |
| [illegible] | Fiber Optic Cables | 1 | 0.83 | . | 4.28 | . |
| [illegible] | Fiber Optic Interconnectors | 146 | 0.16 | 0.32 | 12.73 | 48.74 |
| [illegible] | Fiber Optic Accessories & Supplies | 24 | 0.1 | 0.02 | 0.66 | 0.63 |
| [illegible] | Fiber Optic Kits & Sets | 3 | 0.83 | 0 | 26.37 | 44.57 |
| [illegible] | Fiber Optic Misc | 1 | 0.83 | . | 1.83 | . |
| 6105 | Motors, Electrical | 24866 | 12.3 | 61.5 | 89.59 | 7059.82 |
| 6110 | Electrical Control Equip | 13216 | 6.14 | 75.96 | 38.98 | 1132.41 |
| 6115 | Generators & Generator Sets Elect | 7484 | 10.68 | 68.62 | 44.89 | 316.76 |
| 6120 | Transformers - Distribution & Power Sta | 572 | 116.15 | 164.06 | 305.97 | 704.51 |
| 6125 | Converters, Electrical Rotating | 628 | 9.69 | 21.21 | 40.76 | 288.36 |
| 6130 | Converters, Electrical Nonrotating | 13880 | 5.36 | 21.86 | 28.88 | 114.13 |
| 6135 | Batteries, Primary | 33366 | 1.3 | 2.36 | 84.31 | 1216.17 |
| 6140 | Batteries, Secondary | 41672 | 16.97 | 27.3 | 113.76 | 4108.51 |
| 6145 | Wire & Cable Electrical | 116221 | 3.13 | 16.73 | 484.3 | 17657.86 |
| 6150 | Misc Electric Power & Distribution Equip | [illegible] | 5.12 | 20.69 | 33.14 | 316.96 |
| 6160 | Misc Electric Power | 4568 | 3.66 | 0.12 | 9.82 | 20.02 |
| 6210 | Indoor & Outdoor Elec Lighting Fixtures | 61100 | 1.16 | 5.29 | 25.61 | 1434.79 |
| [illegible] | Electric Vehicular Lights & Fixtures | 166164 | 1.37 | 2.61 | 7.82 | 316.16 |
| [illegible] | Electric portable & Hand Lighting Equip | 35666 | 4.51 | 11.74 | 86.7 | 406.29 |
| [illegible] | Electric Lamps | 287766 | 0.42 | 1.39 | 26.36 | 423.62 |
| [illegible] | Ballasts, Lampholders & Starters | 13307 | 1.48 | 3.6 | 29.86 | 128.83 |
| [illegible] | Nonelectrical Lighting Fixtures | 21331 | 1.64 | 1.89 | 33.67 | 104.66 |
| [illegible] | Traffic & Transit Signal Systems | 9 | 2.74 | 1.7 | 2.74 | 1.7 |
| [illegible] | Shipboard Alarm & Signal Systems | 434 | 12.33 | 28.86 | 36.16 | 282.64 |
| [illegible] | Railway Alarm & Signal Systems | 2776 | 0.92 | 1.51 | 2.97 | 13.76 |
| [illegible] | Misc Alarm & Signal Systems | 13166 | 2.48 | 6.88 | 18.58 | 444.2 |
| [illegible] | Drugs, Biologicals & Official Reagents | [illegible] | 1.57 | 5.6 | 89.87 | 1666.97 |
| [illegible] | Medicated Cosmetics & Toiletries | 3867 | 3.96 | 6.77 | 126.63 | 767.36 |
| [illegible] | Surgical Dressing Materials | 76526 | 2.51 | 6.12 | 66.36 | 376.36 |
| [illegible] | Medical & Surgical Instruments Equip & Sup | 288777 | 1.66 | 4.67 | 67.9 | 832.59 |
| [illegible] | Dental Instruments Equip & Supplies | 114861 | 1.76 | 16.61 | 18.64 | 666.62 |
| [illegible] | X-Ray Equip & Supplies - Medical & Dental | [illegible] | 42.35 | 386.33 | [illegible] | 11104.51 |
| [illegible] | Hospital Furniture Equip Utensils & Supply | [illegible] | 14.36 | 32.66 | 226.66 | 1613.87 |
| [illegible] | Hospital & Surgical Clothing | [illegible] | 7.83 | 16.93 | 141.86 | 1667.2 |
| [illegible] | Ophthalmic Instruments Equip & Supplies | [illegible] | 6.69 | 7.16 | 16.16 | 236.61 |
| [illegible] | Medical Sets Kits & Outfits | [illegible] | 41.65 | 236.51 | 646.43 | 2766.44 |
| [illegible] | In Vitro Diagnostic Substances, Reagents | 16717 | 1.56 | 6.66 | 24.27 | 414.41 |
| [illegible] | Navigational Instruments | 4766 | 1.5 | 16.63 | 11.2 | 62.36 |
| [illegible] | Flight Instruments | [illegible] | 0.56 | 3.61 | 4.66 | 36.71 |
| [illegible] | Automatic Pilot Mechanisms Airborne Gyro | 3634 | 0.45 | 1.16 | 4.42 | 36.73 |
| [illegible] | Engine Instruments | [illegible] | 0.64 | 2.34 | 3.61 | 69.64 |
| [illegible] | Electrical & Electronic Measuring Instrument | [illegible] | 0.66 | 6.1 | 3.46 | 36.77 |
| [illegible] | Chemical Analysis Instruments | [illegible] | 2.77 | 6.67 | 26.61 | 113.76 |
| [illegible] | Physical Properties Testing Equip | 6167 | 6.65 | 36.36 | 16.46 | 66.57 |
| [illegible] | Laboratory Equip & Supplies | [illegible] | 3.62 | 16.36 | 66.1 | 4446.31 |
| [illegible] | Time Measuring Instruments | 16726 | 0.66 | 2.32 | 3.27 | 16.63 |
| [illegible] | Optical Instruments | 7266 | 1.67 | 3.66 | 6.46 | 23.66 |
| [illegible] | Geophysical & Astronomical Instruments | 361 | 1.66 | 1.61 | 136.66 | 1266.2 |
| [illegible] | Meteorological Instruments & Apparatus | 3671 | 1.34 | 4.62 | 22.61 | 244.32 |
| [illegible] | Hazard-Detecting Instruments & Apparatus | [illegible] | 2.16 | 1.61 | 16.66 | 66.66 |
| [illegible] | Scales & Balances | 3376 | 23.66 | 46.66 | 66.46 | 247.41 |
| [illegible] | Drafting Surveying & Mapping Instruments | 6337 | 6.66 | 23.22 | 16.14 | 163.64 |
| [illegible] | Liquid & Gas Flow Measuring Instruments | [illegible] | 1.94 | 7.66 | 6.57 | 166.66 |
| [illegible] | Pressure Temp Humidity Instruments | 77646 | 1.44 | 7.74 | 6.61 | 266.26 |
| [illegible] | Combination & Misc Instruments | [illegible] | 2.67 | 6.64 | 7.67 | 42.61 |
| 6710 | Cameras Motion Picture | 163 | 1.26 | 1.77 | 21.16 | 66.64 |
| 6720 | Cameras Still Picture | 636 | 1.82 | 3.66 | 7.81 | 23.36 |
| 6730 | Photographic Projection Equip | [illegible] | 16.61 | 26.26 | 37.41 | 76.6 |
| 6740 | Photo Developing & Finishing Equip | 1726 | 3.46 | 16.76 | 26.22 | [illegible] |
| 6750 | Photographic Supplies | 24647 | 6.47 | 41.2 | 166.66 | 1266.61 |
| 6760 | Photographic Equip & Accessories | 2627 | 2.16 | 4.66 | 24.66 | 146.36 |
| 6770 | Film Processed | 16 | 6.6 | 6.46 | 1.66 | 2.26 |
| 6780 | Photographic Sets Kits & Outfits | 62 | 14.74 | 12.6 | 66.61 | 266.47 |
| 6810 | Chemicals | 36661 | 37.61 | 66.37 | 666.02 | 6766.66 |
| 6820 | Dyes | 131 | 7.47 | 23.33 | 37.12 | 62.26 |
| 6830 | Gases Compressed & Liquefied | 4136 | 44.97 | 64.97 | 2046.16 | 60132.34 |
| 6840 | Pest Control Agents & Disinfectants | 13113 | 11.89 | 46.27 | 231.59 | 1771.31 |
| 6850 | Misc Chemical Specialties | 56671 | 67.27 | 166.72 | 717.3 | 4764.71 |
| 6910 | Training Aids | 831 | 5.31 | 8.3 | 97.43 | 382.21 |

Table C1. Continued

| FSC | Description | Freq | Mean Weight | Std Dev Weight | Mean Est Weight | Std Dev Est Weight |
|---|---|---|---|---|---|---|
| 6920 | Armament Training Devices | 1763 | 10.61 | 88.73 | 238.31 | 4831.84 |
| 6930 | Operational Training Devices | 341 | 1.96 | 12.93 | 6.66 | 18.01 |
| 6940 | Communication Training Devices | 85 | 0.82 | 0.38 | 3.66 | 7.94 |
| 7010 | ADPE Configuration | 1167 | 2.17 | 5.1 | 3.67 | 9.4 |
| 7020 | ADP Central Processing Unit - Analog | 137 | 4.79 | 0.59 | 14.68 | 15.86 |
| 7021 | ADP Central Processing Unit - Digital | 169 | 0.33 | 0.29 | 0.78 | 1.07 |
| 7022 | ADP Central Processing Unit - Hybrid | 6061 | 2.27 | 4.67 | 18.61 | 128.41 |
| 7025 | ADP Input/Output & Storage Devices | 66 | 4.29 | 2.46 | 37.31 | 60.17 |
| 7030 | ADP Software | 1471 | 0.78 | 1.44 | 3.47 | 18.14 |
| 7035 | ADP Support Equip | 184 | 0.7 | 0.98 | 28.25 | 83.33 |
| 7045 | ADP Supplies & Support Equip | 14825 | 1.44 | 3.4 | 64.44 | 338.78 |
| 7050 | ADP Components | 1476 | 2.09 | 2.38 | 6.42 | 17.19 |
| 7105 | Household Furniture | 5422 | 16.78 | 18.71 | 864.83 | 9119.11 |
| 7110 | Office Furniture | 880 | 81.02 | 27.42 | 769.78 | 3387.82 |
| 7125 | Cabinets Lockers Bins & Shelving | 1399 | 242.58 | 90.2 | 868.28 | 1838.03 |
| 7195 | Misc Furniture & Fixtures | 63 | 68.04 | 64.38 | 687.37 | 1866.72 |
| 7210 | Household Furnishings | 13634 | 7.37 | 12.74 | 866.61 | 6808.4 |
| 7240 | Household & Commercial Util Containers | 6646 | 6.07 | 4.83 | 148.59 | 720 |
| 7290 | Misc Household Furnishings Appliances | 723 | 3.09 | 0 | 66.77 | 187.18 |
| 7310 | Food Cooking Baking Serving Equip | 25372 | 30.86 | 102.28 | 104 | 694.82 |
| 7320 | Kitchen Equip & Appliances | 6366 | 78.91 | 246.37 | 178.93 | 437.59 |
| 7330 | Kitchen Hand Tools & Utensils | 2033 | 13.86 | 10.59 | 837.59 | 8788.54 |
| 7340 | Cutlery & Flatware | 2320 | 0.17 | 0.13 | 11.85 | 32.83 |
| 7350 | Tableware | 1305 | 1.59 | 3.47 | 62.58 | 488.33 |
| 7360 | Sets Kits & Outfits Food Prep & Serving | 6361 | 14.31 | 30.13 | 68.85 | 360.98 |
| 7430 | Typewriters & Office Type Composing | 66 | 97.27 | 0 | 408.68 | 841.47 |
| 7450 | Office Type Sound Recording Repro Mach | 64 | 2.28 | 3.8 | 3.78 | 6.18 |
| 7460 | Visible Record Equip | 42 | 11.06 | 28.32 | 38.19 | 97.37 |
| 7510 | Office Supplies | 908 | 3.21 | 87.7 | 8.61 | 118.88 |
| 7520 | Office Devices & Accessories | 1123 | 0.88 | 0.78 | 10.32 | 48.68 |
| 7530 | Stationery & Record Forms | 1728 | 91.04 | 328.14 | 688.86 | 3821.28 |
| 7540 | Standard Forms | 186 | 0.8 | 0.08 | 16.43 | 43.98 |
| 7610 | Books & Pamphlets | 880 | 4.12 | 9.84 | 28.21 | 62.88 |
| 7630 | Newspapers & Periodicals | 1 | 3 | . | 3 | . |
| 7640 | Maps Atlases Charts & Globes | 82 | 0.46 | 0.8 | 6.82 | 23.34 |
| 7670 | Microfilm Processed | 2 | 0.34 | 0 | 0.34 | 0 |
| 7690 | Misc Printed Matter | 28889 | 0.22 | 0.78 | 6.48 | 278.8 |
| 7910 | Floor Polishers & Vacuum Cleaners | 184 | 74.41 | 6.48 | 883.09 | 1816.87 |
| 7920 | Brooms Brushes Mops & Sponges | 361 | 1.12 | 3.3 | 11.78 | 97.72 |
| 7930 | Cleaning - Polishing Compounds & Preps | 187 | 33.68 | 14.81 | 141.87 | 464.82 |
| 8020 | Paint & Artists Brushes | 82 | 2.78 | 0 | 17.17 | 23.27 |
| 8030 | Preservative & Sealing Compounds | 9 | 2.78 | 0 | 22.98 | 28.8 |
| 8040 | Adhesives | 18 | 2.48 | 0.8 | 7.88 | 8.81 |
| 8105 | Bags & Sacks | 2091 | 12.09 | 11.1 | 822.09 | 12017.78 |
| 8110 | Drums & Cans | 8788 | 48.46 | 84.71 | 1128.38 | 3321.88 |
| 8115 | Boxes Cartons & Crates | 1480 | 37.89 | 47.78 | 188.1 | 291.38 |
| 8120 | Gas Cylinders | 4478 | 82.43 | 84.51 | 1004.22 | 6848.9 |
| 8125 | Bottles & Jars | 3482 | 4.2 | 4.98 | 80.88 | 138.23 |
| 8130 | Reels & Spools | 382 | 18.83 | 28.44 | 208.38 | 714.68 |
| 8135 | Packaging & Packing Bulk Materials | 48 | 7.37 | 8 | 798.08 | 3217.81 |
| 8140 | Ammunition & Nuclear Ordnance Boxes | 4471 | 1.72 | 7.9 | 33.82 | 817.21 |
| 8145 | Specialized Shipping & Storage Container | 298 | 11.84 | 81.4 | 290.14 | 982.8 |
| 8305 | Textile Fabrics | 21514 | 2.31 | 17.79 | 3861.07 | 188882 |
| 8310 | Yarn & Thread | 2734 | 2.18 | 8.31 | 14.84 | 67.47 |
| 8315 | Notions & Apparel Findings | 21463 | 0.4 | 1.89 | 48.32 | 372.51 |
| 8320 | Padding & Stuffing Materials | 38 | 3.33 | 4.57 | 5738.88 | 11288.88 |
| 8330 | Leather | 1165 | 1.42 | 1.61 | 48.8 | 183.38 |
| 8335 | Shoe Findings & Soling Materials | 2930 | 0.8 | 3.67 | 18.98 | 88.2 |
| 8340 | Tents & Tarpaulins | 28297 | 68.18 | 161.97 | 588.98 | 6851.19 |
| 8345 | Flags & Pennants | 28808 | 1.8 | 2.82 | 12.21 | 238.28 |
| 8405 | Outerwear Mens | 283243 | 1.58 | 1.44 | 37.08 | 232 |
| 8410 | Outerwear Womens | 108814 | 1.14 | 1.18 | 14.21 | 103.08 |
| 8415 | Clothing Special Purpose | 412132 | 1.73 | 1.57 | 78.89 | 1238.3 |
| 8420 | Underwear & Nightwear Mens | 30868 | 0.3 | 0.1 | 88.88 | 438.68 |
| 8430 | Footwear Mens | 248721 | 4.52 | 1.32 | 104.44 | 4225.58 |
| 8435 | Footwear Womens | 15868 | 2.18 | 0.32 | 13.38 | 37.38 |
| 8440 | Hosiery Handwear & Clothing Access Men | 48087 | 0.23 | 0.22 | 44.52 | 380.5 |
| 8445 | Hosiery Handwear & Clothing Access Women | 5089 | 0.06 | 0.84 | 29.46 | 228.5 |
| 8455 | Badges & Insignia | 128006 | 0.08 | 0.33 | 10.86 | 223.2 |
| 8460 | Luggage | 8863 | 6.24 | 8.88 | 178.98 | 1150.09 |

Table C1. Continued

| PSC | Description | Freq | Mean Weight | Std Dev Weight | Mean Ext Weight | Std Dev Ext Weight |
|---|---|---|---|---|---|---|
| 8465 | Individual Equip | 57280 | 1.33 | 2.37 | 168.87 | 3012.18 |
| 8470 | Armor Personal | 11489 | 2.7 | 3.87 | 176.78 | 2862.1 |
| 8520 | Toilet Soap Shaving Prep - Dentifrices | 2 | 11.79 | 0 | 111.88 | 25 |
| 8530 | Personal Toiletry Articles | 1180 | 2.42 | 0.52 | 32.87 | 249.48 |
| 8540 | Toiletry Paper Products | 889 | 23.88 | 4.82 | 528.16 | 1632.83 |
| 8940 | Special Dietary Foods - Specialty Prep | 8 | 13.07 | 8.88 | 1880.87 | 3846.25 |
| 9110 | Fuels Solid | 308 | 0.11 | 0.06 | 57.9 | 121.41 |
| 9150 | Oils Greases Cutting Lubricants & Hyd | 108870 | 60.32 | 141.44 | 884.9 | 11423.01 |
| 9160 | Misc Waxes Oils & Fats | 1884 | 28.82 | 88.88 | 544.11 | 6877 |
| 9310 | Paper & Paperboard | 51 | 2028.27 | 628.12 | 45128.84 | 61738.88 |
| 9320 | Rubber Fabricated Materials | 11888 | 6.46 | 8.83 | 77.33 | 523.33 |
| 9330 | Plastics Fabricated Materials | 22410 | 17.53 | 28.38 | 168.48 | 608.42 |
| 9340 | Glass Fabricated Materials | 14273 | 14.16 | 22.82 | 88.03 | 288.78 |
| 9350 | Refractories & Fire Surfacing Matls | 887 | 38.58 | 60.88 | 1482.74 | 2848.12 |
| 9390 | Misc Fabricated Nonmetallic Matls | 21424 | 1.87 | 5.83 | 21.88 | 230.42 |
| 9505 | Wire Nonelectrical Iron & Steel | 14885 | 3.13 | 10.18 | 38.83 | 232.38 |
| 9510 | Bars & Rods Iron & Steel | 28128 | 7.28 | 20.42 | 200.18 | 843.32 |
| 9515 | Plate Sheet & Strip Iron & Steel | 17840 | 334.81 | 851.01 | 1537.81 | 15281.34 |
| 9520 | Structural Shapes Iron & Steel | 13217 | 5.17 | 7.4 | 633.43 | 2774 |
| 9525 | Wire Nonelectrical Nonferrous Base Metals | 5740 | 2.88 | 0 | 28.48 | 280.48 |
| 9530 | Bars & Rods Nonferrous Base Metal | 15088 | 8.01 | 33.16 | 80.51 | 342.47 |
| 9535 | Plate Sheet Strip-Nonferrous Base Metal | 30057 | 70.43 | 148.87 | 338.72 | 1330.58 |
| 9540 | Structural Shapes Nonferrous Base Metal | 10616 | 1.13 | 4.28 | 61.88 | 482.88 |
| 9545 | Plate Sheet Strip & Wire Precious Metal | 38 | 0.03 | 0.03 | 0.88 | 1.52 |
| 9620 | Minerals Natural & Synthetic | 105 | 2.08 | 3.18 | 6.71 | 11.31 |
| 9630 | Additive Metal Materials & Master Alloys | 48 | 1 | 0.01 | 134.81 | 448.81 |
| 9640 | Iron & Steel Primary & Semifinished Prod | 188 | 24.11 | 16.24 | 448.88 | 1384.83 |
| 9650 | Nonferrous Base Metal Refinery | 887 | 3.72 | 11.88 | 1421.88 | 11070.15 |
| 9660 | Precious Metals Primary Forms | 138 | 8.88 | 0 | 85880.11 | [illegible] |
| 9905 | Signs Advertising Displays | 102 | 24.13 | 40.41 | 134.38 | 448.38 |
| 9920 | Smokers Articles & Matches | 88 | 13.48 | 0 | 90.31 | 109.81 |
| 9925 | Ecclesiastical Equip Furnishings & Supplies | 648 | 11.83 | 14.84 | 47.08 | 203.21 |
| 9930 | Memorials Cemetery Mortuary Equip | 327 | 10.37 | 18.5 | 282.82 | 888.11 |
| [illegible] | Misc Items | 11 | 10.03 | 20.33 | 348.75 | 775.24 |

Table D1: 67-Product Aggregation Scheme.

| Aggregate Product | Product Groups | Material Description |
|---|---|---|
| 1 | 1000 | Weapons |
| 2 | 1200 | Fire Control Equipment |
| 3 | 1400 | Guided Missile Components |
| 4 | 1500/1600 | Acft & Airframe Struct Comp; Acft Comps & Accessorie |
| 5 | 1700 | Acft Launch, Ldg & Gnd Handling Equip |
| 6 | 2000 | Ship & Marine Equip |
| 7 | 2200 | Railway Equip |
| 8 | 2400 | Tractors |
| 9 | 2500 | Vehicular Equip Comps |
| 10 | 2600 | Acft Tires |
| 11 | 2800 | Engines, Turbines, & Comps-Acft & Non- Acft |
| 12 | 2900 | Engine Accessories-Acft & Non-Acft |
| 13 | 3000 | Mech Power Transmission Equip |
| 14 | 3100 | Bearings |
| 15 | 3200 | Woodworking Machinery & Equip |
| 16 | 3400 | Metalworking Machinery |
| 17 | 3500 | Service & Trade Equip |
| 18 | 3600 | Special Industry Machinery |
| 19 | 3700 | Agricultural Machinery |
| 20 | 3800 | Const, Mining, Excavating & Equip |
| 21 | 3900 | Materials Handling Equip |
| 22 | 4000 | Rope, Cable, Chain, & Fittings |
| 23 | 4100 | Refrigeration & Air Cond Equip |
| 24 | 4200 | Fire Fighting, Rescue & Safety Equip |
| 25 | 4300 | Pumps & Compressors |
| 26 | 4400 | Furnace, Steam Plant, Drying Equip |
| 27 | 4500 | Plumbing, Heating & Sanitation |
| 28 | 4600 | Water Purification & Sewage Treatment Equip |
| 29 | 4700 | Pipe, Tube & Hose |
| 30 | 4800 | Valves |
| 31 | 4900 | Maintenance & Repair Shop Equip |
| 32 | 5100 | Hand Tools |
| 33 | 5200 | Measuring Tools |
| 34 | 5300 | Hardware & Abrasives |
| 35 | 5400 | Prefab Structures & Scaffolding |
| 36 | 5500 | Lumber, Millwork, Plywood & Veneer |
| 37 | 5600 | Construction & Building Material |
| 38 | 5800 | Communication Equip |
| 39 | 5900 | Electrical & Electronic Equip Comps |
| 40 | 6000 | Fiber Optics Mtls, Comps, Assys |
| 41 | 6100 | Electric Wire, & Power & Distribution |
| 42 | 6200 | Lighting Fixtures & Lamps |
| 43 | 6300 | Alarm & Signal Systems |
| 44 | 6500 | Medical Dental & Veterinary Equip |
| 45 | 6600 | Instruments & Laboratory Equip |
| 46 | 6700 | Photographic Equip |
| 47 | 6800 | Chemicals & Chemical Products |
| 48 | 6900 | Training Aids & Devices |
| 49 | 7000 | General Purpose Adpe, Software, Supplies |
| 50 | 7100 | Furniture |
| 51 | 7200 | Household & Coml Furnishings & Appliances |
| 52 | 7300 | Kitchen & Food Prep Equip |
| 53 | 7400 | Office Machines, Visible record Equip |
| 54 | 7500 | Office Supplies & Devices |
| 55 | 7600 | Books, Maps & Other Pubs |
| 56 | 7900 | Cleaning Equip & Supplies |
| 57 | 8000 | Brushes, Paints, Sealers,& Adhesives |
| 58 | 8100 | Containers, Packaging & Packing Supplies |
| 59 | 8300 | Textiles, Furs,Notions, Tents |
| 60 | 8400 | Clothing |
| 61 | 8500 | Toiletries |
| 62 | 8900 | Specialty Prep |
| 63 | 9100 | Fuels, Lubricants, Oils & Waxes |
| 64 | 9300 | Nonmetallic Fabricated Mt'ls |
| 65 | 9500 | Metal Bars, Sheets and Shapes |
| 66 | 9600 | Ores,Minerals & Their Primary Products |
| 67 | 9900 | Miscellaneous |

Table D2. This table provides the summary statistics (total requisitions, average weight per requisition, standard deviation of weight per requisition, average extended weight per requisition, and standard deviation of extended weight per requisition) for the 67-product aggregation scheme .

| Aggregate Product | Frequency | Mean Weight | Std Dev Weight | Mean Ext Weight | Std Dev Ext Weight |
|---|---|---|---|---|---|
| 1 | 76894 | 1.9488 | 4.388 | 38.35 | 437.59 |
| 2 | 6829 | 1.2261 | 4.883 | 6.4 | 33.39 |
| 3 | 16889 | 2.3856 | 4.614 | 16.16 | 82.88 |
| 4 | 282955 | 2.4888 | 6.888 | 16.08 | 162.11 |
| 5 | 24494 | 12.8488 | 36.62 | 68.96 | 382.67 |
| 6 | 16485 | 24.5146 | 71.882 | 895.21 | 33888.32 |
| 7 | 184 | 18.7418 | 18.887 | 876.97 | 1074.23 |
| 8 | 34 | 82.8491 | 128.413 | 97.41 | 218.8 |
| 9 | 842889 | 12.8863 | 34.834 | 41.83 | 1887.43 |
| 10 | 1881 | 14.8842 | 11.812 | 88.37 | 117.83 |
| 11 | 83223 | 11.4163 | 43.143 | 78.25 | 888.88 |
| 12 | 476240 | 5.1885 | 18.867 | 24.2 | 1817.98 |
| 13 | 234808 | 6.2826 | 26.332 | 28.17 | 788.06 |
| 14 | 337687 | 1.3614 | 23.611 | 14.49 | 836.58 |
| 15 | 2864 | 20.7067 | 128.008 | 32.03 | 163.44 |
| 16 | 108876 | 6.0686 | 40.478 | 51.34 | 724.67 |
| 17 | 3871 | 32.8186 | 113.388 | 66.82 | 247.27 |
| 18 | 8286 | 20.4624 | 60.272 | 108.75 | 1308.26 |
| 19 | 2189 | 27.2889 | 128.675 | 72.98 | 348.98 |
| 20 | 13122 | 66.7654 | 166.763 | 280.85 | 2104.37 |
| 21 | 18128 | 61.8864 | 188.382 | 1086.37 | 23888.06 |
| 22 | 122888 | 37.4884 | 144.134 | 332.31 | 34784.86 |
| 23 | 82765 | 35.8746 | 131.848 | 188.38 | 7441.86 |
| 24 | 87888 | 8.8827 | 38.12 | 164.12 | 2181.98 |
| 25 | 147889 | 6.8843 | 42.861 | 37.43 | 2281.28 |
| 26 | 11188 | 23.4188 | 88.148 | 148.38 | 2288.83 |
| 27 | 48808 | 13.8113 | 88.888 | 91.71 | 887.22 |
| 28 | 3788 | 18.1882 | 88.888 | 178.38 | 888.28 |
| 29 | 843225 | 1.9484 | 14.888 | 88.73 | 7378.38 |
| 30 | 214740 | 5.3715 | 28.883 | 23.82 | 836.14 |
| 31 | 78883 | 11.8842 | 38.823 | 88.88 | 844.2 |
| 32 | 1788 | 0.783 | 1.838 | 3.08 | 8.23 |
| 33 | 1885 | 2.35 | 8.133 | 8.73 | 83.28 |
| 34 | 4381188 | 8.8136 | 8.122 | 8.87 | 388.41 |
| 35 | 8888 | 41.8882 | 188.888 | 478.87 | 3888.38 |
| 36 | 4425 | 8.198 | 28.824 | 11718.88 | 83783.88 |
| 37 | 1818 | 84.8888 | 188.82 | 4827.88 | 28818.82 |
| 38 | 61347 | 2.8832 | 8.848 | 28.82 | 388.88 |
| 39 | 2813833 | 8.8828 | 7.882 | 7.87 | 342.84 |
| 40 | 388 | 0.1788 | 8.482 | 8.78 | 28.48 |
| 41 | 388888 | 7.8888 | 33.488 | 214.82 | 11188.28 |
| 42 | 483888 | 1.1381 | 4.288 | 23.88 | 888.43 |
| 43 | 18377 | 2.4288 | 8.827 | 13.78 | 488.83 |
| 44 | 1282831 | 2.8888 | 38.288 | 88.88 | 1888.08 |
| 45 | 388848 | 1.8441 | 10.881 | 14.81 | 1287.82 |
| 46 | 32182 | 8.0883 | 37.288 | 122.07 | 1118.4 |
| 47 | 112441 | 48.8818 | 128.288 | 778.21 | 18881.48 |
| 48 | 3040 | 8.0871 | 48.828 | 184.44 | 3478.8 |
| 49 | 28374 | 1.8873 | 3.714 | 38.88 | 288.43 |
| 50 | 6124 | 61.8837 | 82.88 | 842.13 | 7841.17 |
| 51 | 22808 | 6.7824 | 10.282 | 888.88 | 8381.81 |
| 52 | 43773 | 32.3147 | 124.338 | 123.84 | 1882.88 |
| 53 | 184 | 40.437 | 48.884 | 182.41 | 384.81 |
| 54 | 3888 | 48.4172 | 234.821 | 481.88 | 2888.88 |
| 55 | 21883 | 0.3838 | 2.377 | 7.3 | 273.16 |
| 56 | 712 | 28.8788 | 30.178 | 187.01 | 848 |
| 57 | 79 | 2.8821 | 0.383 | 18.7 | 21.88 |
| 58 | 28428 | 32.8428 | 88.427 | 883.34 | 4888.88 |
| 59 | 101837 | 18.8288 | 83.113 | 824.83 | 88888.08 |
| 60 | 1321488 | 1.8811 | 2.123 | 84.27 | 2080.88 |
| 61 | 2121 | 12.1384 | 11.884 | 288.31 | 1148.2 |
| 62 | 8 | 13.07 | 8.887 | 1880.87 | 3848.25 |
| 63 | 111282 | 88.4781 | 148.487 | 878.38 | 11333.11 |
| 64 | 70761 | 11.8878 | 60.782 | 138.42 | 2108.87 |
| 65 | 138888 | 82.874 | 388.888 | 481.27 | 8884 |
| 66 | 1141 | 6.7877 | 13.342 | 10783.14 | 88831.04 |
| 67 | 1147 | 12.5788 | 18.484 | 124.28 | 840.48 |

Table D3. 44-Product aggregation scheme

| Aggregate Product | FSC's | Material Description |
|---|---|---|
| 1 | 1005 - 1095 | Weapons |
| 2 | 1210 - 1290 | Fire Control Equip, Optical Sighting Equip |
| 3 | 1420 - 1450 | Guided Missile Comps |
| 4 | 1560 | Acft & Airframe Struct Comps |
| | 1610 - 1680 | Acft Comps & Accessories |
| | 2620 | Tires |
| 5 | 1710 - 1740 | Acft Launch, Landing, & Ground Handling Equip |
| 6 | 2010 - 2090 | Ship & Marine Equip |
| 7 | 2230/2240/2250 | Railway Equip |
| | 2410/2420 | Tractors |
| | 2510 - 2590 | Vehicular Equip |
| 8 | 2805/2815/2825/ | Engines, Turbines, & Comps - Non Acft |
| | 2835/2845/2895/ | Gas Reciprocating & Diesel Engines; Rocket Engines |
| | 2895 | Steam & Water Turbines; Gas Turbines, |
| 9 | 2810/2840 | Engines, Turbines, & Comps - Acft |
| 10 | 2910/2920/2930 | Engine Accessories - Non Acft; Fuel Systems, |
| | 2940/2950/2990 | Electrical, Cooling Systems, Air & Oil Filters, Turbo |
| 11 | 2915/2925/2935 | Engine Accessories - Acft; Fuel Systems, Electrical |
| | 2945/2995 | Cooling Systems, Air & Oil Filters |
| 12 | 3010 - 3040 | Mech Power Transmission Equip |
| | 3110 - 3130 | Bearings |
| 13 | 3210/3220/3230 | Woodworking Machinery & Equip |
| | 3405-3465 | Metal Working Machinery & Equip |
| 14 | 3510-3590 | Service & Trade Equip: Laundry & Dry Cleaning, Shoe Repair, Sewing Machines |
| 15 | 3610-3695 | Special Industry Equip |
| 16 | 3710-3770 | Agricultural Machinery & Equip: Soil Prep & Harvesting Equip |
| | 3805-3895 | Construction, Mining, Excavating, & Hwy Equip |
| 17 | 3910-3990 | Materials Handling Equip |
| 18 | 4010/4020/4030 | Rope, Cable, Chain, & Fitting |
| 19 | 4110-4140 | Refrigeration & Air Cond Equip |
| 20 | 4210-4240 | Fire Fighting, Rescue & Safety Equip |
| 21 | 4310/4320/4330 | Pumps & Compressors |
| | 4410-4460 | Furnace, Steam Plant, & Drying Equip |
| 22 | 4510-4540 | Plumbing, Heating & Sanitation Equip |
| | 4610-4630 | Water Purification & Sewage Treatment Equip |
| 23 | 4710-4730 | Pipe, Tube & Hose |
| 24 | 4810/4820 | Valves |
| 25 | 4910-4940 | Maintenance & Repair Shop Equip |
| 26 | 5305-5335 | Hardware & Abrasives |
| | 5340-5395 | |
| 27 | [illegible] | Metal Screening |
| | 5410-5450 | Prefab Structures & Scaffolding |
| | 5510-5530 | Lumber, Millwork, Plywood & Veneer |
| | [illegible] | Building, Glass, Tile, Brick & Block Fencing/Misc Constr Matl |
| 28 | 5805-5895 | Communication Equip |
| 29 | 5905-5999 | Electrical & Electronic Equip Comps |
| | 6010-6060 | Fiber Optic Matls, Comps, & Assys |
| 30 | 6105-6150 | Electric Wire, & Power & Distribution |
| 31 | 6210-6260 | Lighting Fixtures & Lamps |
| | 6310-6350 | Alarm & Signal Systems |
| 32 | 6505-6550 | Medical, Dental, & Veterinary Equip |
| 33 | 6605-6695 | Instruments & Laboratory Equip |
| 34 | 6710-6780 | Photographic Equip |
| 35 | 6810-6850 | Chemicals & Chemical Products |
| 36 | 6910-6940 | Training Aids & Devices |
| 37 | 7010-7050 | Genl Purpose Adpe, Software, Supplies |
| 38 | 7105-7195 | Furniture |
| | 7210/7240/7290 | House Furnishings |
| | 7310-7360 | Food Prep & Serving Equip |
| | 7430-7490 | Office Machines |
| | 7510-7540 | Office Supplies & Devices |
| | 7610-7690 | Books, Maps & Other Publications |
| | 7710-7750 | Musical Instruments, Phonographs, & TV |
| | 8020/8030/8040 | Paint Brushes, Preservative Components, Adhesives |
| 39 | 8105-8145 | Containers, Packaging & Packing Supplies |
| 40 | 8305-8345 | Textiles, Furs, Notions, Tents |
| | 8405-8475 | Clothing |
| | 8510-8540 | Toiletries |
| 41 | 9110/9150/9160 | Fuels, Lubricants, Oils & Waxes |
| 42 | 9310-9390 | Nonmetallic Fabricated Matls |
| 43 | 9505-9545 | Metal Bars, Sheets and Shapes |
| | 9620-9660 | Ores, Minerals |
| 44 | 9650 | Ores, Minerals & Their Primary Products |
| | 8940 | Specialty Prep Dietary Foods |
| | 5110/5120/5130 | Hand Tools |
| | 5210/5220/5280 | Measuring Tools |

Table D4. This table provides the summary statistics (total requisitions, average weight per requisition, standard deviation of weight per requisition, average extended weight per requisition, and standard deviation of extended weight per requisition) for the 44-product aggregation scheme .

| Aggregate Product | Frequency | Mean Weight | Std Dev Weight | Mean Ext Weight | Std Dev Ext Weight |
|---|---|---|---|---|---|
| 1 | 78864 | 1.65 | 4.57 | 35.88 | 437.09 |
| 2 | 8829 | 1.22 | 4.58 | 6.40 | 33.39 |
| 3 | 10888 | 2.30 | 4.61 | 15.16 | 62.66 |
| 4 | 254877 | 2.58 | 8.70 | 15.31 | 161.85 |
| 5 | 24864 | 12.85 | 35.62 | 66.95 | 352.67 |
| 6 | 16456 | 24.51 | 71.96 | 585.21 | 33568.32 |
| 7 | 842758 | 12.06 | 34.84 | 41.73 | 1657.32 |
| 8 | 75102 | 14.00 | 47.70 | 83.03 | 668.31 |
| 9 | 18121 | 0.70 | 2.00 | 63.57 | 1394.80 |
| 10 | 457152 | 5.32 | 15.71 | 21.10 | 481.74 |
| 11 | 21088 | 1.62 | 11.20 | 91.44 | 8853.98 |
| 12 | 571975 | 3.37 | 24.40 | 20.11 | 688.19 |
| 13 | 109629 | 6.44 | 52.37 | 50.87 | 715.65 |
| 14 | 3571 | 32.92 | 113.27 | 66.82 | 247.27 |
| 15 | 5295 | 20.48 | 60.27 | 109.75 | 1308.26 |
| 16 | 15311 | 52.55 | 162.18 | 233.93 | 1953.73 |
| 17 | 19128 | 61.89 | 150.28 | 1055.37 | 23596.05 |
| 18 | 122656 | 37.47 | 144.13 | 332.31 | 34794.65 |
| 19 | 52765 | 35.87 | 131.05 | 158.26 | 7441.85 |
| 20 | 87903 | 9.63 | 36.12 | 154.12 | 2191.95 |
| 21 | 158725 | 9.11 | 47.37 | 45.27 | 2291.74 |
| 22 | 52803 | 13.92 | 68.89 | 97.80 | 595.54 |
| 23 | 943225 | 1.95 | 16.07 | 55.73 | 7379.39 |
| 24 | 214740 | 5.37 | 28.96 | 23.82 | 835.14 |
| 25 | 78983 | 11.88 | 39.62 | 56.69 | 844.20 |
| 26 | 4369777 | 0.60 | 7.95 | 7.99 | 308.58 |
| 27 | 13752 | 32.04 | 141.79 | 4640.62 | 54528.19 |
| 28 | 61247 | 2.05 | 5.85 | 28.02 | 358.85 |
| 29 | 2613919 | 0.69 | 7.08 | 7.56 | 342.92 |
| 30 | 308500 | 7.66 | 33.49 | 214.92 | 11169.36 |
| 31 | 479865 | 1.17 | 4.37 | 23.34 | 678.66 |
| 32 | 1262831 | 3.00 | 35.30 | 69.99 | 1695.06 |
| 33 | 358349 | 1.94 | 10.66 | 14.91 | 1267.82 |
| 34 | 32102 | 9.03 | 37.21 | 122.07 | 1115.40 |
| 35 | 112441 | 49.53 | 125.21 | 775.21 | 18061.48 |
| 36 | 3040 | 8.09 | 45.53 | 154.44 | 3476.80 |
| 37 | 25374 | 1.69 | 3.71 | 36.95 | 265.43 |
| 38 | 101209 | 22.37 | 98.28 | 271.90 | 3674.63 |
| 39 | 25426 | 32.54 | 50.43 | 663.34 | 4925.69 |
| 40 | 1425544 | 3.19 | 22.75 | 126.08 | 23087.42 |
| 41 | 111262 | 59.48 | 140.49 | 875.36 | 11333.11 |
| 42 | 70701 | 11.86 | 60.79 | 135.42 | 2109.67 |
| 43 | 136230 | 62.50 | 359.09 | 488.23 | 8485.96 |
| 44 | 4519 | 4.35 | 11.40 | 39.17 | 321.37 |

Table D5 29-Product aggregation scheme

| Aggregate Product | FSC | Material Description |
|---|---|---|
| 1 | 1005 - 1095 | Weapons |
| 2 | 1210 - 1290 | Fire Control Equip, Optical Sighting Equip |
| | 1420 - 1450 | Guided Missile Components |
| 3 | 1560 | Acft & Airframe Structural Components |
| | 1610-1680 | Acft Components & Accessories |
| | 1710 - 1740 | Acft Launch, Landing, & Ground Handling Equip |
| | 2620 | Tires |
| | 2810/2840 | Engines, Turbines, & Components - Acft |
| | 2915/2925/2935/2945 | Engine, Accessories - Acft, Fuel Systems |
| | 2995 | Electrical, Cooling Systems, Air & Oil Filters |
| 4 | 2010 - 2090 | Ship & Marine Equip |
| 5 | 2230/2240/2250 | Railway Equip |
| | 2410/2420 | Tractors |
| | 2510-2590 | Vehicular Equip |
| 6 | 2805/2815/2820/2830/<br>2835/2845/2850/2895 | Engines, Turbines, & Comps - Non Acft<br>Gas Reciprocating &Diesel Engines, Steam & Water Turbines, Gas Turbines, Rocket Engines |
| | 2910/2920/2930/2940/<br>2950/2990 | Engine Accessories - Non Acft, Fuel Systems, Electrical Cooling Systems, Air & Oil Filters, Turbo Superchargers |
| 7 | 3010 - 3040 | Mech Power Transmission Equip |
| | 3110 - 3130 | Bearing |
| 8 | 3210/3220/3230 | Woodworking Machinery & Equip |
| | 3405 -3465 | Metal Working Machinery & Equip |
| | 3510 - 3590 | Service & Trade Equip, Laundry & Dry Cleaning Equip, Shoe Repair, Sewing Machines |
| | 3610 - 3695 | Special Industry Equip |
| | 3910 - 3990 | Materials Handling Equip |
| 9 | 3710 - 3770 | Agricultural Mech & Equip, Soil Prep & Harvesting Equip |
| | 3805 - 3895 | Construction, Mining, Excavating, & Highway Equip |
| 10 | 4010 - 4030 | Rope, Cable, Chain, & Fittings |
| 11 | 4110 - 4140 | Refrigeration & Air Conditioning Equip |
| | 4510 - 4540 | Plumbing, Heating, & Sanitation Equip |
| | 4610 - 4630 | Water Purification & Sewage Treatment Equip |
| | 4710 - 4730 | Pipe, Tube & Hose |
| 12 | 4210 - 4240 | Fire Fighting, Rescue, & Safety Equip |
| 13 | 4310 - 4330 | Pumps & Compressors |
| | 4410 - 4460 | Furnace, Steam Plant, & Drying Equip |
| 14 | 4810 - 4820 | Valves |
| 15 | 4910 - 4940 | Maintenance & Repair Shop Equip |
| 16 | 5305 - 5365 | Hardware & Abrasives |
| | 5410 - 5450 | Prefab Structures & Scaffolding |
| | 5510 - 5530 | Lumber, Millwork, Plywood & Veneer |
| | 5620/[illegible] | Fencing, Misc Construction Matl |
| 17 | 5805 - 5895 | Communication |
| 18 | 5905 - 5999 | Electrical & Electronic Equip Comps |
| | 6010 - 6060 | Fiber Optic Matls, Comps & Assys |
| 19 | 6105 - 6150 | Electric Wire, & Powe & Distribution |
| | 6210 - 6260 | Lighting Fixtures & Lamps |
| | 6310 - 6350 | Alarm & Signal Systems |
| 20 | 6505 - 6550 | Medical, Dental, & Veterinary Equip |
| 21 | 6605 -6699 | Instruments & Laboratory Equip |
| 22 | 6710 - 6780 | Photographic Equip |
| | 6910 - 6940 | Training Aids & Devices |
| | 7010 - 7050 | General Purpose ADPE, Software, Supplies |
| 23 | 6810 - 6850 | Chemicals & Chemical Products |
| 24 | 7105 - 7540 | Furniture |
| | 7210/7240/7290 | House Furnishings |
| | 7310 - 7360 | Food Prep & Serving Equip |
| | 7430 - 7490 | Office Machines |
| | 7510 - 7540 | Office Supplies & Devices |
| | 7610 - 7690 | Books, Maps, & Other Publications |
| | 7710 - 7730 | Musical Instruments, Phonographs, & TV |
| | 8020/8030/8040 | Paint Brushes, Preservative Components, Adhesives |
| | 8105 - 8145 | Containers, Packaging, & Packing Supplies |
| 25 | 8305 - 8345 | Textiles, Furs, Notions, Tents |
| | 8405 - 8470 | Clothing |
| | 8510 - 8540 | Toiletries |
| 26 | 9110/9150/9160 | Fuels, Lubricants, Oils, & Waxes |
| 27 | 9310 - 9390 | Nonmetallic Fabricated Matls |
| 28 | 9505 - 9545 | Metal Bars, Shheets, & Shapes |
| | 9620 - 9660 | Ores, Minerals |
| 29 | 9900 | Miscellaneous |
| | 8940 | Specialty Prep Dietary Foods |
| | 5110/5120/5130 | Hand Tools |
| | 5210/5220/5280 | Measuring Tools |

Table D6. This table provides the summary statistics (total requisitions, average weight per requisition, standard deviation of weight per requisition, average extended weight per requisition, and standard deviation of extended weight per requisition) for the 29-product aggregation scheme .

| Aggregate Product | Frequency | Mean Weight | Std Dev Weight | Mean Ext Weight | Std Dev Ext Weight |
|---|---|---|---|---|---|
| 1 | 76664 | 1.65 | 4.57 | 35.88 | 437.09 |
| 2 | 19717 | 1.82 | 4.63 | 11.23 | 51.83 |
| 3 | 318950 | 3.21 | 13.27 | 27.12 | 2307.51 |
| 4 | 16455 | 24.51 | 71.96 | 585.21 | 33568.32 |
| 5 | 842758 | 12.06 | 34.84 | 41.73 | 1657.32 |
| 6 | 532254 | 6.54 | 23.28 | 29.84 | 512.66 |
| 7 | 571975 | 3.37 | 24.40 | 20.11 | 688.19 |
| 8 | 137623 | 15.38 | 78.55 | 193.16 | 8830.46 |
| 9 | 15311 | 52.55 | 162.18 | 233.93 | 1953.73 |
| 10 | 122656 | 37.47 | 144.13 | 332.31 | 34794.65 |
| 11 | 1048793 | 4.26 | 37.35 | 63.00 | 7195.74 |
| 12 | 87903 | 9.63 | 36.12 | 154.12 | 2191.95 |
| 13 | 158725 | 9.11 | 47.37 | 45.27 | 2291.74 |
| 14 | 214740 | 5.37 | 28.96 | 23.82 | 835.14 |
| 15 | 78993 | 11.88 | 39.62 | 56.69 | 844.20 |
| 16 | 4403529 | 0.70 | 11.35 | 22.45 | 3073.53 |
| 17 | 61247 | 2.05 | 5.65 | 28.02 | 358.65 |
| 18 | 2613919 | 0.69 | 7.06 | 7.57 | 342.92 |
| 19 | 786465 | 3.70 | 21.42 | 98.00 | 6993.49 |
| 20 | 1262631 | 3.00 | 35.30 | 69.99 | 1695.08 |
| 21 | 356349 | 1.94 | 10.66 | 14.91 | 1267.82 |
| 22 | 60516 | 5.90 | 29.28 | 88.01 | 1139.51 |
| 23 | 112441 | 49.53 | 125.21 | 775.21 | 18061.48 |
| 24 | 126635 | 24.41 | 90.82 | 350.49 | 3960.76 |
| 25 | 1425544 | 3.19 | 22.75 | 126.08 | 23087.42 |
| 26 | 111262 | 59.48 | 140.49 | 875.38 | 11333.11 |
| 27 | 70701 | 11.86 | 60.79 | 135.42 | 2109.67 |
| 28 | 136230 | 62.50 | 359.09 | [illegible]8.23 | 8485.96 |
| 29 | 4519 | 4.35 | 11.40 | [illegible]17 | 321.37 |

Table D7: 49-Product aggregation scheme.

| Aggregate Product | FSC | Material Description |
|---|---|---|
| 1 | 1005-1095 | Weapons |
| 2 | 1210-1287 | Fire Control Equipment |
| | 1420-1450 | Guided Missile Components |
| 3 | 1560 | Airframe Structural Comps |
| | 1610-1680 | Aircraft Comps & Accessories |
| | 1710-1740 | Aicft Launching,Ldg, & Gnd Handling Equip |
| | 2620 | Tires |
| 4 | 2010-2090 | Ship & Marine Equip |
| 5 | 2230-2250 | Railway Equip |
| | 2410/2420 | Tractors |
| | 2510 | Vehicular Cab Body Frame; Structural Comps |
| 6 | 2520 | Vehicular Power Transmission Comps |
| 7 | 2530 | Vehicular Brake Steering Axle; Wheel Comps |
| 8 | 2540 | Vehicular Furniture & Accessories |
| 9 | 2590 | Misc Vehicular Comps |
| 10 | 2805-2895 | Engines, Turbines, & Comps |
| | 2910-2995 | Engine Accessories |
| 11 | 3010-3040 | Mech Power Transmission Equip |
| 12 | 3110-3130 | Bearings |
| 13 | 3210-3230 | Woodworking Machinery & Equip |
| | 3405-3465 | Metalworking Equip |
| | 3510-3590 | Service & Trade Equip |
| | 3610-3695 | Special Industry Equip |
| 14 | 3710-3770 | Agricultural Machinery & Equip |
| | 3805-3895 | Const, Mining ,Excavating & Hwy |
| | 3910-3990 | Matls Handling Equip |
| 15 | 4010-4030 | Rope, Cable, Chain & Fittings |
| 16 | 4210-4240 | Fire Fighting, Rescue & Safety Equip |
| 17 | 4110-4140 | Refrigeration & Air Cond |
| | 4310-4330 | Pumps & Compressors |
| | 4410-4460 | Furnace, Steam Plant, Drying Equip |
| | 4510-4540 | Plumbing, Heating & Sanitation Equip |
| | 4610-4630 | Water Purification & Sewage Treatment Equip |
| 18 | 4710 | Pipe & Tube |
| 19 | 4720 | Hose & Tubing Flexible |
| 20 | 4730 | Fittings, Hose, Pipe, & Tube |
| 21 | 4810-4820 | Valves |
| 22 | 4910-4940 | Maintenance & Repair Shop Equip |
| | 5110-5133 | Hand Tools |
| | 5210-5280 | Measuring Tools |
| 23 | 5305 | Screws |
| 24 | 5306 | Bolts |
| | 5307 | Studs |
| 25 | 5310 | Nuts & Washers |
| | 5340 | Misc Hardware |
| | 5355 | Knobs & Pointers |
| | 5360 | Coil, Flat & Wire Springs |
| | 5365 | Rings Shims & Spacers |

Table D7. Continued

| Aggregate Product | FSC | Material Description |
|---|---|---|
| 26 | 5315 | Nails Keys & Pins |
| 27 | 5320 | Rivets |
| | 5325 | Fastening Devices |
| 28 | 5330 | Packing & Gasket Matls |
| 29 | 5335 | Metal Screening |
| | 5345 | Disks & Stones Abrasives |
| | 5350 | Abrasive Matls |
| | 5410-5450 | Prefabricated Structures; Scaffolding |
| | 5510-5530 | Lumber, Millwork, Plywood & Veneer |
| | 5620-5680 | Construction &Building Matls |
| 30 | 5805-5895 | Communication Equip |
| | 5905-5970 | Electrical Equip: Resistors, Capacitors, Filters, Networks, Circuit Breakers |
| 31 | 5975-5999 | Electrical Hardware |
| | 6010-6099 | Fiber Optics |
| 32 | 6105-6140 | Electric Wire & Power & Distribution |
| | 6150/6160 | Misc Power & Distribution |
| 33 | 6145 | Electrical Wire & Cable |
| 34 | 6210-6260 | Lighting Fixtures & Lamps |
| | 6310-6350 | Alarm & Signal Systems |
| 35 | 6505 | Drums, Biologicals |
| | 6508 | Medicated Cosmetics & Tioletries |
| 36 | 6510 | Surgical Dressing Matls |
| | 6532 | Hospital & Surgical Clothing |
| 37 | 6515 | Medical Surgical Instruments Equip |
| | 6540 | Opticians Instruments Equip |
| | 6545 | Medical Sets Kits & Outfits |
| | 6550 | In Vitro Diagnostic Substances |
| 38 | 6520 | Dental Instruments Equip |
| | 6525 | X-Ray Equip Supplies-Medical/Dental |
| 39 | 6530 | Hospital Furniture Equip |
| 40 | 6810-6850 | Chemical & Chemical Products |
| 41 | 6910-6940 | Training Aids & Devices |
| | 7010-7050 | Adpe, Software,Supplies |
| 42 | 7105-7195 | Furniture |
| | 7210-7290 | Household & Coml Furniture |
| | 7310-7360 | Food Prep & Serving Equip |
| | 7430-7490 | Office Machines |
| 43 | 7510-7540 | Office Supplies |
| | 7610-7690 | Books, Maps & Other Publications |
| | 7910-7930 | Cleaning Equip & Supplies |
| | 8020-8040 | Brushes, Paints, Sealers & Adhesives |
| 44 | 8105-8145 | Cotainers, Packaging & Packing Supplies |
| | 9310-9390 | Nonmetallic Fabricated Matls |
| 45 | 8305-8345 | Textiles |
| | 8405/8410 | Outerwear |
| 46 | 8415-8470 | Clothing |
| | 8510-8540 | Toiletries |
| 47 | 8940 | Special Prep Dietary Foods |
| | 9110-9160 | Fuels,Lubricants, Oils & Waxes |
| 48* | 9505-9545 | Metal Bars & Sheets |
| | 9620-9680 | Ores,Minerals |
| | 9905-9999 | Misc |
| 49* | 6605-6695 | Instruments & Laboratory Equip |
| | 6710-6780 | Photographic Equip |

Table D8. This table provides the summary statistics (total requisitions, average weight per requisition, standard deviation of weight per requisition, average extended weight per requisition, and standard deviation of extended weight per requisition) for the 49-product aggregation scheme .

| Aggregate Product | Frequency | Mean Weight | Std Dev Weight | Mean Ext Weight | Std Dev Ext Weight |
|---|---|---|---|---|---|
| 1 | 76864 | 1.65 | 4.57 | 35.88 | 437.09 |
| 2 | 19717 | 1.82 | 4.63 | 11.23 | 51.83 |
| 3 | 279741 | 3.49 | 13.79 | 19.90 | 187.45 |
| 4 | 16455 | 24.51 | 71.96 | 585.21 | 33568.32 |
| 5 | 148096 | 22.06 | 38.66 | 55.79 | 433.91 |
| 6 | 80748 | 11.53 | 36.06 | 56.02 | 662.87 |
| 7 | 204992 | 11.92 | 47.08 | 52.42 | 3277.37 |
| 8 | 311445 | 8.68 | 21.89 | 28.09 | 350.68 |
| 9 | 97477 | 8.39 | 27.43 | 29.63 | 338.48 |
| 10 | 571463 | 6.18 | 22.62 | 33.18 | 1788.67 |
| 11 | 234908 | 6.26 | 25.33 | 28.17 | 756.06 |
| 12 | 337067 | 1.35 | 23.51 | 14.49 | 636.56 |
| 13 | 118495 | 7.87 | 55.80 | 53.98 | 743.17 |
| 14 | 34439 | 57.73 | 155.75 | 660.17 | 17637.96 |
| 15 | 122656 | 37.47 | 144.13 | 332.31 | 34794.65 |
| 16 | 87903 | 9.63 | 36.12 | 154.12 | 2191.95 |
| 17 | 264293 | 15.41 | 76.37 | 78.32 | 3779.35 |
| 18 | 109665 | 4.41 | 30.36 | 263.81 | 8003.25 |
| 19 | 237074 | 3.93 | 22.65 | 77.72 | 13671.49 |
| 20 | 596466 | 0.70 | 5.52 | 8.73 | 192.25 |
| 21 | 214740 | 5.37 | 28.96 | 23.82 | 835.14 |
| 22 | 82357 | 11.46 | 38.87 | 54.61 | 826.87 |
| 23 | 587830 | 0.50 | 1.68 | 10.87 | 431.50 |
| 24 | 386548 | 0.48 | 2.77 | 8.67 | 113.39 |
| 25 | 1773715 | 0.64 | 6.97 | 8.74 | 301.44 |
| 26 | 243968 | 0.66 | 7.61 | 10.77 | 487.65 |
| 27 | 305445 | 0.24 | 2.05 | 7.79 | 469.42 |
| 28 | 1092186 | 0.72 | 12.53 | 4.38 | 125.01 |
| 29 | 13817 | 31.99 | 141.47 | 4618.92 | 54400.68 |
| 30 | 2222066 | 0.58 | 7.04 | 5.43 | 360.98 |
| 31 | 453100 | 1.42 | 7.10 | 20.80 | 237.93 |
| 32 | 190279 | 10.43 | 40.44 | 68.71 | 3233.20 |
| 33 | 116221 | 3.13 | 15.73 | 454.30 | 17657.85 |
| 34 | 479965 | 1.17 | 4.37 | 23.34 | 678.66 |
| 35 | 640967 | 1.58 | 5.63 | 60.05 | 1963.62 |
| 36 | 91173 | 3.56 | 6.33 | 69.28 | 513.56 |
| 37 | 351596 | 3.34 | 48.83 | 70.72 | 924.78 |
| 38 | 119174 | 3.46 | 73.10 | 42.09 | 2305.57 |
| 39 | 59901 | 14.35 | 32.93 | 228.59 | 1813.87 |
| 40 | 112441 | 49.53 | 125.21 | 775.21 | 18061.48 |
| 41 | 28414 | 2.37 | 15.42 | 49.52 | [illegible] |
| 42 | 74956 | 27.72 | 101.36 | 344.57 | 4228.77 |
| 43 | 26253 | 7.11 | 87.13 | 64.40 | 960.95 |
| 44 | 96127 | 17.33 | 58.94 | 275.06 | 3121.70 |
| 45 | 460794 | 5.31 | 39.78 | 228.17 | 40455.04 |
| 46 | 964750 | 2.17 | 2.41 | 77.32 | 2432.62 |
| 47 | 111270 | 59.47 | 140.48 | 875.43 | 11332.74 |
| 48 | 137377 | 62.09 | 357.63 | 485.19 | 8450.67 |
| 49 | 388451 | 2.53 | 14.92 | 23.77 | 1256.27 |

## APPENDIX E

Table E1: Top 259 U. S cities as identified in SAILS (table continued on the next page)

| City | State | 3-Digit Zip |
|---|---|---|
| Springfield | MA | 011 |
| Pittsfield | MA | 012 |
| Worcester | MA | 016 |
| Boston | MA | 021 |
| New Bedford | MA | 027 |
| Providence | RI | 029 |
| Manchester | NH | 031 |
| Portsmouth | NH | 038 |
| Portland | ME | 041 |
| Lewiston | ME | 042 |
| Bangor | ME | 044 |
| Burlington | VT | 054 |
| Hartford | CN | 061 |
| New London | CT | 063 |
| Bridgeport | CT | 066 |
| Newark | NJ | 071 |
| Paterson | NJ | 075 |
| Long Branch | NJ | 077 |
| Atlantic City | NJ | 084 |
| Trenton | NJ | 086 |
| New Brunswick | NJ | 089 |
| New York | NY | 100 |
| Nassau-Suffolk | NY | 115 |
| Albany | NY | 122 |
| Newburgh | NY | 125 |
| Glens Falls | NY | 128 |
| Syracuse | NY | 132 |
| Utica | NY | 135 |
| Binghamton | NY | 139 |
| Buffalo | NY | 142 |
| Rochester | NY | 146 |
| Elmira | NY | 149 |
| Pittsburgh | PA | 152 |
| Johnstown | PA | 159 |
| Sharon | PA | 161 |
| Erie | PA | 165 |
| Altoona | PA | 166 |
| State College | PA | 168 |
| Harrisburg | PA | 171 |
| York | PA | 174 |
| Lancaster | PA | 176 |
| Williamsport | PA | 177 |
| Allentown | PA | 181 |
| Northeast Penna | PA | 185 |
| Philadelphia | PA | 191 |
| Reading | PA | 196 |
| Wilmington | DE | 198 |
| Washington | DC | 200 |
| Baltimore | MD | 212 |
| Cumberland | MD | 215 |
| Hagerstown | MD | 217 |
| Charlottesville | VA | 229 |
| Richmond | VA | 232 |
| Norfolk | VA | 235 |
| Petersburg | VA | 238 |
| Roanoke | VA | 240 |
| Lynchburg | VA | 245 |
| Charleston | WV | 253 |
| Huntington | WV | 257 |
| Wheeling | WV | 260 |
| Parkersburg | WV | 261 |
| Greensboro | NC | 274 |
| Raleigh | NC | 276 |
| Charlotte | NC | 282 |
| Fayetteville | NC | 283 |

| City | State | 3-Digit Zip |
|---|---|---|
| Wilmington | NC | 284 |
| Jacksonville | NC | 285 |
| Hickory | NC | 286 |
| Ashville | NC | 287 |
| Columbia | SC | 292 |
| Charleston | SC | 294 |
| Florence | SC | 295 |
| Greenville | SC | 296 |
| Rock Hill | SC | 297 |
| Atlanta | GA | 303 |
| Athens | GA | 306 |
| Augusta | GA | 309 |
| Macon | GA | 312 |
| Savannah | GA | 314 |
| Albany | GA | 317 |
| Columbus | GA | 319 |
| Jacksonville | FL | 322 |
| Tallahassee | FL | 323 |
| Panama City | FL | 324 |
| Pensacola | FL | 325 |
| Gainesville | FL | 326 |
| Orlando | FL | 328 |
| Melbourne | FL | 329 |
| Miami | FL | 331 |
| West Palm Beach | FL | 334 |
| Tampa | FL | 336 |
| Lakeland | FL | 338 |
| Fort Myers | FL | 339 |
| Birmingham | AL | 352 |
| Tuscaloosa | AL | 354 |
| Florence | AL | 356 |
| Huntsville | AL | 358 |
| Gadsden | AL | 359 |
| Montgomery | AL | 361 |
| Anniston | AL | 362 |
| Mobile | AL | 366 |
| Nashville | TN | 372 |
| Chattanooga | TN | 374 |
| Johnson City | TN | 376 |
| Knoxville | TN | 379 |
| Memphis | TN | 381 |
| Jackson | MS | 392 |
| Biloxi | MS | 395 |
| Louisville | KY | 402 |
| Lexington | KY | 405 |
| Owensboro | KY | 423 |
| Columbus | OH | 432 |
| Toledo | OH | 436 |
| Steubenville | OH | 439 |
| Cleveland | OH | 441 |
| Akron | OH | 443 |
| Youngstown | OH | 445 |
| Canton | OH | 447 |
| Mansfield | OH | 449 |
| Cincinnati | OH | 452 |
| Dayton | OH | 454 |
| Lima | OH | 458 |
| Indianapolis | IN | 462 |
| Gary | IN | 464 |
| South Bend | IN | 466 |
| Fort Wayne | IN | 468 |
| Kokomo | IN | 469 |
| Muncie | IN | 473 |
| Bloomington | IN | 474 |
| Evansville | IN | 477 |

Table E1: Continued

| City | State | 3-DIGIT ZIP |
|---|---|---|
| Terre Haute | IN | 478 |
| Lafayette | IN | 479 |
| Detroit | MI | 482 |
| Flint | MI | 485 |
| Saginaw | MI | 486 |
| Lansing | MI | 489 |
| Kalamazoo | MI | 490 |
| Jackson | MI | 492 |
| Grand Rapids | MI | 495 |
| Des Moines | IA | 503 |
| Waterloo | IA | 507 |
| Sioux City | IA | 511 |
| Dubuque | IA | 520 |
| Cedar Rapids | IA | 524 |
| Davenport | IA | 528 |
| Milwaukee | WI | 532 |
| Madison | WI | 537 |
| Green Bay | WI | 543 |
| Wausau | WI | 544 |
| La Crosse | WI | 546 |
| Eau Claire | WI | 547 |
| Appleton | WI | 549 |
| Minneapolis- St Paul | MN | 554 |
| Duluth | MN | 558 |
| Rochester | MN | 559 |
| St Cloud | MN | 563 |
| Sioux Falls | SD | 571 |
| Fargo | ND | 581 |
| Grand Forks | ND | 582 |
| Bismarck | ND | 585 |
| Billings | MT | 591 |
| Great Falls | MT | 594 |
| Chicago | IL | 606 |
| Kankakee | IL | 609 |
| Rockford | IL | 611 |
| Peoria | IL | 616 |
| Bloomington | IL | 617 |
| Champaign | IL | 618 |
| Springfield | IL | 627 |
| St Louis | MO | 631 |
| Kansas City | MO | 641 |
| St Joseph | MO | 645 |
| Columbia | MO | 652 |
| Springfield | MO | 658 |
| Lawrence | KS | 660 |
| Topeka | KS | 666 |
| Wichita | KS | 672 |
| Omaha | NE | 681 |
| Lincoln | NE | 685 |
| New Orleans | LA | 701 |
| Lafayette | LA | 705 |
| Lake Charles | LA | 706 |
| Baton Rouge | LA | 708 |
| Shreveport | LA | 711 |
| Monroe | LA | 712 |
| Alexandria | LA | 713 |
| Pine Bluff | AR | 716 |
| Little Rock | AR | 722 |
| Fayetteville | AR | 727 |
| Fort Smith | AR | 729 |
| Oklahoma City | OK | 731 |
| Lawton | OK | 735 |
| Enid | OK | 737 |
| Tulsa | OK | 741 |

| City | State | 3-Digit Zip |
|---|---|---|
| Dallas-Ft Worth | TX | 752 |
| Texarkana | TX | 755 |
| Long View | TX | 756 |
| Tyler | TX | 757 |
| Wichita Falls | TX | 763 |
| Killeen | TX | 765 |
| Waco | TX | 767 |
| San Angelo | TX | 769 |
| Houston | TX | 770 |
| Galveston | TX | 775 |
| Beaumont | TX | 777 |
| Bryan | TX | 778 |
| Victoria | TX | 779 |
| San Antonio | TX | 782 |
| Corpus Christi | TX | 784 |
| Mcallen | TX | 785 |
| Austin | TX | 787 |
| Amarillo | TX | 791 |
| Lubbock | TX | 794 |
| Abilene | TX | 796 |
| Odessa | TX | 797 |
| El Paso | TX | 799 |
| Denver | CO | 802 |
| Fort Collins | CO | 805 |
| Greeley | CO | 806 |
| Colorado Springs | CO | 809 |
| Pueblo | CO | 810 |
| Casper | WY | 826 |
| Boise | ID | 837 |
| Salt Lake City | UT | 841 |
| Provo | UT | 846 |
| Phoenix | AZ | 850 |
| Tucson | AZ | 857 |
| Albuquerque | NM | 871 |
| Las Cruces | NM | 880 |
| Las Vegas | NV | 891 |
| Reno | NV | 895 |
| Los Angeles | CA | 900 |
| San Diego | CA | 921 |
| Riverside | CA | 925 |
| Anaheim | CA | 928 |
| Oxnard | CA | 930 |
| Bakersfield | CA | 933 |
| Fresno | CA | 937 |
| Salinas | CA | 939 |
| San Franciscon | CA | 941 |
| Vallejo | CA | 945 |
| San Jose | CA | 951 |
| Stockton | CA | 952 |
| Santa Rosa | CA | 954 |
| Sacramento | CA | 958 |
| Chicago | CA | 959 |
| Redding | CA | 960 |
| Portland | OR | 972 |
| Salem | OR | 973 |
| Eugene | OR | 974 |
| Medford | OR | 975 |
| Seattle | WA | 981 |
| Bellingham | WA | 982 |
| Tacoma | WA | 984 |
| Olympia | WA | 985 |
| Yakima | WA | 989 |
| Spokane | WA | 992 |
| Richland | WA | 993 |

Table E2. This table provides the 113-customer aggregations by city and three-digit zip code.

| CITY | STATE | 3-DIGIT ZIP CODE |
|---|---|---|
| LOS ANGELES | CA | 900 |
| CHICAGO | IL | 606 |
| PHILADELPHIA | PA | 191 |
| BOSTON | MA | 021 |
| SAN FRANCISCO | CA | 941 |
| WASHINGTON | DC | 200 |
| DALLAS-FT WORTH | TX | 752 |
| NASSAU-SUFFOLK | NY | 115 |
| ST LOUIS | MO | 631 |
| BALTIMORE | MD | 212 |
| ATLANTA | GA | 303 |
| ANAHEIM | CA | 928 |
| NEWARK | NJ | 071 |
| SAN DIEGO | CA | 921 |
| MIAMI | FL | 331 |
| DENVER | CO | 802 |
| SEATTLE | WA | 981 |
| TAMPA | FL | 336 |
| RIVERSIDE | CA | 925 |
| PHOENIX | AZ | 850 |
| PORTLAND | OR | 972 |
| NEW ORLEANS | LA | 701 |
| INDIANAPOLIS | IN | 462 |
| COLUMBUS | OH | 432 |
| SAN ANTONIO | TX | 782 |
| SACRAMENTO | CA | 958 |
| ROCHESTER | NY | 146 |
| SALT LAKE CITY | UT | 841 |
| MEMPHIS | TN | 381 |
| LOUISVILLE | KY | 402 |
| PROVIDENCE | RI | 029 |
| NASHVILLE | TN | 372 |
| OKLAHOMA CITY | OK | 731 |
| DAYTON | OH | 454 |
| NORFOLK | VA | 235 |
| JACKSONVILLE | FL | 322 |
| ORLANDO | FL | 328 |
| WORCESTER | MA | 016 |
| NE PENNA | PA | 186 |
| RICHMOND | VA | 232 |
| OMAHA | NE | 681 |
| AUSTIN | TX | 787 |
| TUCSON | AZ | 857 |
| OXNARD | CA | 930 |
| RALEIGH | NC | 276 |
| WILMINGTON | DE | 198 |
| LONGBRANCH | NJ | 077 |
| TACOMA | WA | 984 |
| EL PASO | TX | 799 |
| LAS VEGAS | NV | 891 |
| ALBUQUERQUE | NM | 871 |
| HARRISBURG | PA | 171 |
| CHARLESTON | SC | 294 |
| CHATTANOOGA | TN | 374 |
| PORTSMOUTH | NH | 038 |
| COLUMBIA | SC | 292 |
| BAKERSFIELD | CA | 933 |

| CITY | STATE | 3-DIGIT ZIP CODE |
|---|---|---|
| LITTLE ROCK | AR | 722 |
| DAVENPORT | IA | 528 |
| SHREVEPORT | LA | 711 |
| STOCKTON | CA | 952 |
| SPOKANE | WA | 992 |
| VALLEJO | CA | 945 |
| AUGUSTA | GA | 309 |
| CORPUS CHRISTI | TX | 784 |
| JACKSON | MS | 392 |
| COLCRADO SPRINGS | CO | 809 |
| UTICA | NY | 135 |
| EVANSVILLE | IN | 477 |
| HUNTSVILLE | AL | 358 |
| TRENTON | NJ | 086 |
| SALINAS | CA | 939 |
| PENSACOLA | FL | 325 |
| MELBOURNE | FL | 329 |
| MONTGOMERY | AL | 361 |
| NEWBURGH | NY | 125 |
| MACON | GA | 312 |
| FAYETTEVILLE | NC | 283 |
| COLUMBUS | GA | 319 |
| NEW LONDON | CT | 063 |
| SAVANNAH | GA | 314 |
| KILLEEN | TX | 765 |
| LUBBOCK | TX | 794 |
| SPRINGFIELD | MO | 658 |
| RENO | NV | 895 |
| ATLANTIC CITY | NJ | 084 |
| BILOXI | MS | 395 |
| TOPEKA | KS | 666 |
| BOISE | ID | 837 |
| GREEN BAY | WI | 543 |
| ALEXANDRIA | LA | 713 |
| WILMINGTON | NC | 284 |
| BANGOR | ME | 044 |
| PETERSBURG | VA | 238 |
| TEXARKANA | TX | 755 |
| PUEBLO | CO | 810 |
| ANNISTON | AL | 362 |
| ALBANY | GA | 317 |
| HAGERSTOWN | MD | 217 |
| JACKSONVILLE | NC | 285 |
| LAWTON | OK | 735 |
| BELLINGHAM | WA | 982 |
| GADSDEN | AL | 359 |
| COLUMBIA | MO | 652 |
| GRAND FORKS | ND | 582 |
| LEWISTON | ME | 042 |
| PANAMA CITY | FL | 324 |
| LA CROSSE | WI | 546 |
| SHERMAN | TX | 750 |
| BISMARCK | ND | 585 |
| GREAT FALLS | MT | 594 |
| CASPER | WY | 826 |
| LAWRENCE | KS | 660 |

Table E3 This table provides the 193-customer aggregations by city and three-digit zip code (table continued on the next page)

| CITY | STATE | 3-DIGIT ZIP CODE |
|---|---|---|
| LOS ANGELES | CA | 900 |
| CHICAGO | IL | 606 |
| PHILADELPHIA | PA | 191 |
| BOSTON | MA | 021 |
| SAN FRANCISCO | CA | 941 |
| WASHINGTON | DC | 200 |
| DALLAS-FT WORTH | TX | 752 |
| NASSAU-SUFFOLK | NY | 115 |
| ST LOUIS | MO | 631 |
| BALTIMORE | MD | 212 |
| ATLANTA | GA | 303 |
| ANAHEIM | CA | 928 |
| NEWARK | NJ | 071 |
| SAN DIEGO | CA | 921 |
| MIAMI | FL | 331 |
| DENVER | CO | 802 |
| SEATTLE | WA | 981 |
| TAMPA | FL | 336 |
| RIVERSIDE | CA | 925 |
| PHOENIX | AZ | 850 |
| PORTLAND | OR | 972 |
| NEW ORLEANS | LA | 701 |
| INDIANAPOLIS | IN | 462 |
| COLUMBUS | OH | 432 |
| SAN ANTONIO | TX | 782 |
| SACRAMENTO | CA | 958 |
| ROCHESTER | NY | 146 |
| SALT LAKE CITY | UT | 841 |
| MEMPHIS | TN | 381 |
| LOUISVILLE | KY | 402 |
| PROVIDENCE | RI | 029 |
| NASHVILLE | TN | 372 |
| OKLAHOMA CITY | OK | 731 |
| DAYTON | OH | 454 |
| NORFOLK | VA | 235 |
| JACKSONVILLE | FL | 322 |
| ORLANDO | FL | 328 |
| WORCESTER | MA | 016 |
| NE PENNA | PA | 185 |
| RICHMOND | VA | 232 |
| OMAHA | NE | 681 |
| AUSTIN | TX | 787 |
| TUCSON | AZ | 857 |
| OXNARD | CA | 930 |
| RALEIGH | NC | 276 |
| WILMINGTON | DE | 198 |
| LONGBRANCH | NJ | 077 |
| TACOMA | WA | 984 |
| EL PASO | TX | 799 |
| LAS VEGAS | NV | 891 |

| CITY | STATE | 3-DIGIT ZIP CODE |
|---|---|---|
| ALBUQUERQUE | NM | 871 |
| HARRISBURG | PA | 171 |
| CHARLESTON | SC | 294 |
| CHATTANOOGA | TN | 374 |
| PORTSMOUTH | NH | 038 |
| COLUMBIA | SC | 292 |
| BAKERSFIELD | CA | 933 |
| LITTLE ROCK | AR | 722 |
| DAVENPORT | IA | 528 |
| SHREVEPORT | LA | 711 |
| STOCKTON | CA | 952 |
| SPOKANE | WA | 992 |
| VALLEJO | CA | 945 |
| AUGUSTA | GA | 309 |
| CORPUS CHRISTI | TX | 784 |
| JACKSON | MS | 392 |
| COLORADO SPRINGS | CO | 809 |
| UTICA | NY | 135 |
| EVANSVILLE | IN | 477 |
| HUNTSVILLE | AL | 358 |
| TRENTON | NJ | 086 |
| SALINAS | CA | 939 |
| PENSACOLA | FL | 325 |
| MELBOURNE | FL | 329 |
| MONTGOMERY | AL | 361 |
| NEWBURGH | NY | 125 |
| MACON | GA | 312 |
| FAYETTEVILLE | NC | 283 |
| COLUMBUS | GA | 319 |
| NEW LONDON | CT | 063 |
| SAVANNAH | GA | 314 |
| KILLEEN | TX | 765 |
| LUBBOCK | TX | 794 |
| SPRINGFIELD | MO | 658 |
| RENO | NV | 895 |
| ATLANTIC CITY | NJ | 084 |
| BILOXI | MS | 395 |
| TOPEKA | KS | 666 |
| BOISE | ID | 837 |
| GREEN BAY | WI | 543 |
| ALEXANDRIA | LA | 713 |
| WILMINGTON | NC | 284 |
| BANGOR | ME | 044 |
| PETERSBURG | VA | 238 |
| TEXARKANA | TX | 755 |
| PUEBLO | CO | 810 |
| ANNISTON | AL | 362 |
| ALBANY | GA | 317 |
| HAGERSTOWN | MD | 217 |
| JACKSONVILLE | NC | 285 |

Table E3. Continued

| CITY | STATE | 3-DIGIT ZIP CODE |
|---|---|---|
| LAWTON | OK | 735 |
| BELLINGHAM | WA | 982 |
| GADSDEN | AL | 359 |
| COLUMBIA | MO | 652 |
| GRAND FORKS | ND | 582 |
| LEWISTON | ME | 042 |
| PANAMA CITY | FL | 324 |
| LA CROSSE | WI | 546 |
| SHERMAN | TX | 750 |
| BISMARCK | ND | 585 |
| GREAT FALLS | MT | 594 |
| CASPER | WY | 826 |
| LAWRENCE | KS | 660 |
| CLEVELAND | OH | 441 |
| CINCINNATI | OH | 452 |
| MILWAUKEE | WI | 532 |
| KANSAS CITY | MO | 641 |
| BUFFALO | NY | 142 |
| GREENSBORO | NC | 274 |
| BRIDGEPORT | CT | 066 |
| ALBANY | NY | 122 |
| TOLEDO | OH | 436 |
| TULSA | OK | 741 |
| AKRON | OH | 443 |
| SYRACUSE | NY | 132 |
| GREENVILLE | SC | 296 |
| YOUNGSTOWN | OH | 445 |
| FRESNO | CA | 937 |
| BATON ROUGE | LA | 708 |
| PATERSON | NJ | 075 |
| JOHNSON CITY | TN | 376 |
| FORT WAYNE | IN | 468 |
| MADISON | WI | 537 |
| HUNTINGTON | WV | 257 |
| MCALLEN | TX | 785 |
| KALAMAZOO | MI | 490 |
| MANCHESTER | NH | 031 |
| CHARLESTON | WV | 253 |
| DULUTH | MN | 558 |
| JOHNSTOWN | PA | 159 |
| ROANOKE | VA | 240 |
| GALVESTON | TX | 775 |
| LINCOLN | NE | 685 |
| WHEELING | WV | 260 |
| FAYETTEVILLE | AR | 727 |
| TERRE HAUTE | IN | 478 |
| CHAMPAIGNE | IL | 618 |
| PARKERSBURG | WV | 261 |
| MONROE | LA | 712 |
| FARGO | ND | 581 |

| CITY | STATE | 3-DIGIT ZIP CODE |
|---|---|---|
| FLORENCE | AL | 356 |
| ATHENS | GA | 306 |
| MANSFIELD | OH | 449 |
| SIOUX CITY | IA | 511 |
| ODESSA | TX | 797 |
| CHARLOTSVILLE | VA | 229 |
| FLORENCE | SC | 295 |
| SIOUX FALLS | SD | 571 |
| BILLINGS | MT | 591 |
| GLENS FALLS | NY | 128 |
| KOKOMO | IN | 469 |
| KANKAKEE | IL | 609 |
| BLOOMINGTON | IN | 474 |
| PINE BLUFF | AR | 716 |
| SAN ANGELO | TX | 769 |
| ENID | OK | 737 |
| NEW YORK | NY | 100 |
| DETROIT | MI | 482 |
| HOUSTON | TX | 770 |
| PITTSBURGH | PA | 152 |
| MINNEAPOLIS - ST PA | MN | 554 |
| HARTFORD | CN | 061 |
| BIRMINGHAM | AL | 352 |
| CHARLOTTE | NC | 282 |
| SPRINGFIELD | MA | 011 |
| KNOXVILLE | TN | 379 |
| NEW BEDFORD | MA | 027 |
| LANSING | MI | 489 |
| MOBILE | AL | 366 |
| WICHITA | KS | 672 |
| PEORIA | IL | 616 |
| DES MOINES | IA | 503 |
| LEXINGTON | KY | 405 |
| ROCKFORD | IL | 611 |
| PORTLAND | ME | 041 |
| SAGINAW | MI | 486 |
| FORT SMITH | AR | 729 |
| SPRINGFIELD | IL | 627 |
| YAKIMA | WA | 989 |
| ST CLOUD | MN | 563 |
| FORT COLLINS | CO | 805 |
| CHICAGO | CA | 959 |
| ABILENE | TX | 796 |
| TUSCALOOSA | AL | 354 |
| MEDFORD | OR | 975 |
| WICHITA | TX | 763 |
| BURLINGTON | VT | 054 |
| CUMBERLAND | MD | 215 |
| LAS CRUCES | NM | 880 |

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